CONNECTICUT DEPARTMENT OF TRANSPORTATION
Reconstruction of I-84
Washington Avenue to Pierpont Road
Waterbury, CT
ConnDOT Project No. 151-273
Federal Aid Project No. NHI-84-2 (172) 33

FINAL SCOUR REPORT
BRIDGE NO. 01224

WESTERLY I-84 CROSSING
OVER THE MAD RIVER

Waterbury, Connecticut

Prepared By:

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Newington, CT 06131-7546

July 2006
Revised May 2014

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Executive Summary

This Scour Report has been prepared for the final design of Bridge No. 01224, the westerly I-84 crossing over the Mad River. This bridge is one of six (6) waterway crossings over the river to be constructed under the State Project No. 151-273, improvements to Interstate 84 in Waterbury from Washington Avenue east to Pierpont Road. The subject 4.3-kilometer (2.7 mile) long highway project has been designed by Ammann & Whitney (formerly Berger, Lehman Associates, P.C. – BLA).

The proposed Bridge No. 01224 will be a single span bridge replacing an existing structure that has a center in-river pier. The span length is 29.2 meters (96 ft; measured perpendicular to the abutment faces) which is 0.4 meter (1.3 ft) less than the existing structure. The existing pier will be removed to reduce scour and the potential for debris clogs.

The width of the proposed bridge crossing (measured along the river baseline) will be increased from the existing structure's 40 meters (131 ft) to 91 meters (298 ft) to accommodate not only two additional lanes along the interstate, but also the realignments of the Eastbound Exit 23 On-Ramp and the Eastbound Exit 25 Off-Ramp. The widening will be accomplished on the upstream side of the crossing. The upstream face of the proposed bridge will be located in the approximate vicinity of an existing pedestrian crossing. The pedestrian crossing will be relocated 28 meters (92 ft) upstream of its present location with the pedestrian walkway moved to the easterly riverbank, passing under proposed Bridge No. 01224.

This report finds that the proposed bridge will experience the greatest potential scour during the 500-year event. Particularly for the Abutment #1 (western abutment), the scour depth of approximately 4.71 meters (15.5 ft) is estimated, which is approximately down to an elevation of 102.49 M at the upstream end, undermining the footing. Hence, the footings for the proposed bridge will be placed on piles that have been designed to resist the maximum calculated scour.

Table 1. NBIS Ratings and Scour Related Design Information

Recommended NBIS Item 113 Rating	5 (total scour will expose piles)
Recommended NBIS Item 71 Rating	9
Recommended NBIS Item 61 Rating	8
Scour Risk Designation	Low Risk
Depth of Potential Scour (500-year)	4.72 m (Abutment #1 – West); 2.14 m (Abutment #2 – East)
Foundation Type	Spread footings on Piles
Recommendations	Foundation Designed for Predicted Scour; Riprap Revetment for Main Channel Banks

Reference Reports

The following reports, prepared under separate covers for the project, should be referenced for more detailed information pertinent to the hydrology and hydraulics for the subject reach of the Mad River and the hydraulic design of Bridge No. 01224.

- *Overview Report for Hydraulic Design, CT DEP Flood Management Certification & FEMA Conditional Letter Of Map Revision (CLOMR), Mad River & Beaver Pond Brook, Waterbury, Connecticut* prepared by ConnDOT, July 2006.
- *Hydrologic Report, Mad River* prepared by BLA (Ammann & Whitney), September 1999
- *Hydraulic Analysis for Design Report, Mad River* prepared by ConnDOT, revised April 2014.
- *Final River Relocation Report, Mad River & Beaver Pond Brook* prepared by BLA, January 2004 and revised by ConnDOT, April 2006.
- *Mad River Floodplain/Floodway Analysis Report for FEMA CLOMR & CTDEP Flood Management Certification* prepared by ConnDOT, revised April 2014.

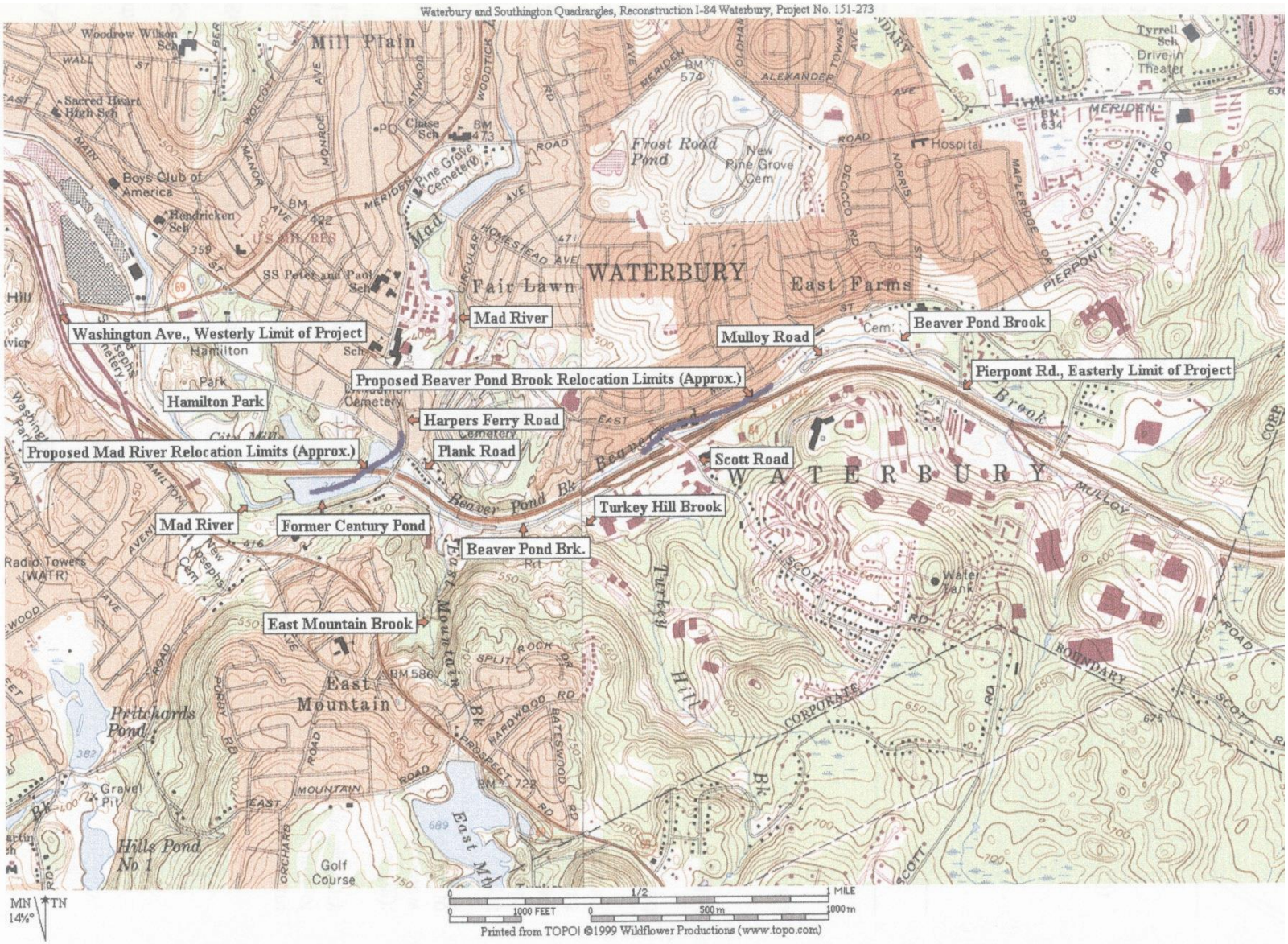
Project Overview

The information presented in this report are mostly derived from the hydraulic analyses performed using the DOT "Design" discharges as presented in the *Hydraulic Analysis for Design Report, Mad River* prepared by ConnDOT, revised April 2014. For complete hydrologic information refer to *Hydrologic Report, Mad River* prepared by BLA (Ammann & Whitney), September 1999. The summarized hydrologic information is shown in the table below.

Table 2. Hydrologic Information

Watershed Area:	62.26 km^2 (24.04 mi^2)- Large Structure
Discharges:	100-Yr: 176.98 cms (6,250 cfs) 500-Yr: 269.01 cms (9,500 cfs) Overtopping: >500 year

See the Overview Report referenced above for an overview of the project, the existing and the proposed project conditions.


Waterbury and Southington Quadrangles, Reconstruction I-84 Waterbury, Project No. 151-273
Washington Ave., Westerly Limit of Project
Mad River
Mulloy Road
Beaver Pond Brook
Pierpont Rd., Easterly Limit of Project
Proposed Beaver Pond Brook Relocation Limits (Approx.)
Hamilton Park
Harpers Ferry Road
Proposed Mad River Relocation Limits (Approx.)
Plank Road
Scott Road
Turkey Hill Brook
Mad River
Former Century Pond
Beaver Pond Brk.
East Mountain Brook
WATERBURY
Mill Plain
Fair Lawn
East Farms
East Mountain
Pritchards Pond
Hills Pond No 1
Frost Road Pond
Golf Course
Radio Towers (WATR)
Boys Club of America
Sacred Heart High Sch
Tyrrell Sch
Drive-in Theater
Hospital
MN 14½°
TN
1/2 MILE
1000 FEET
500 m
1000 m
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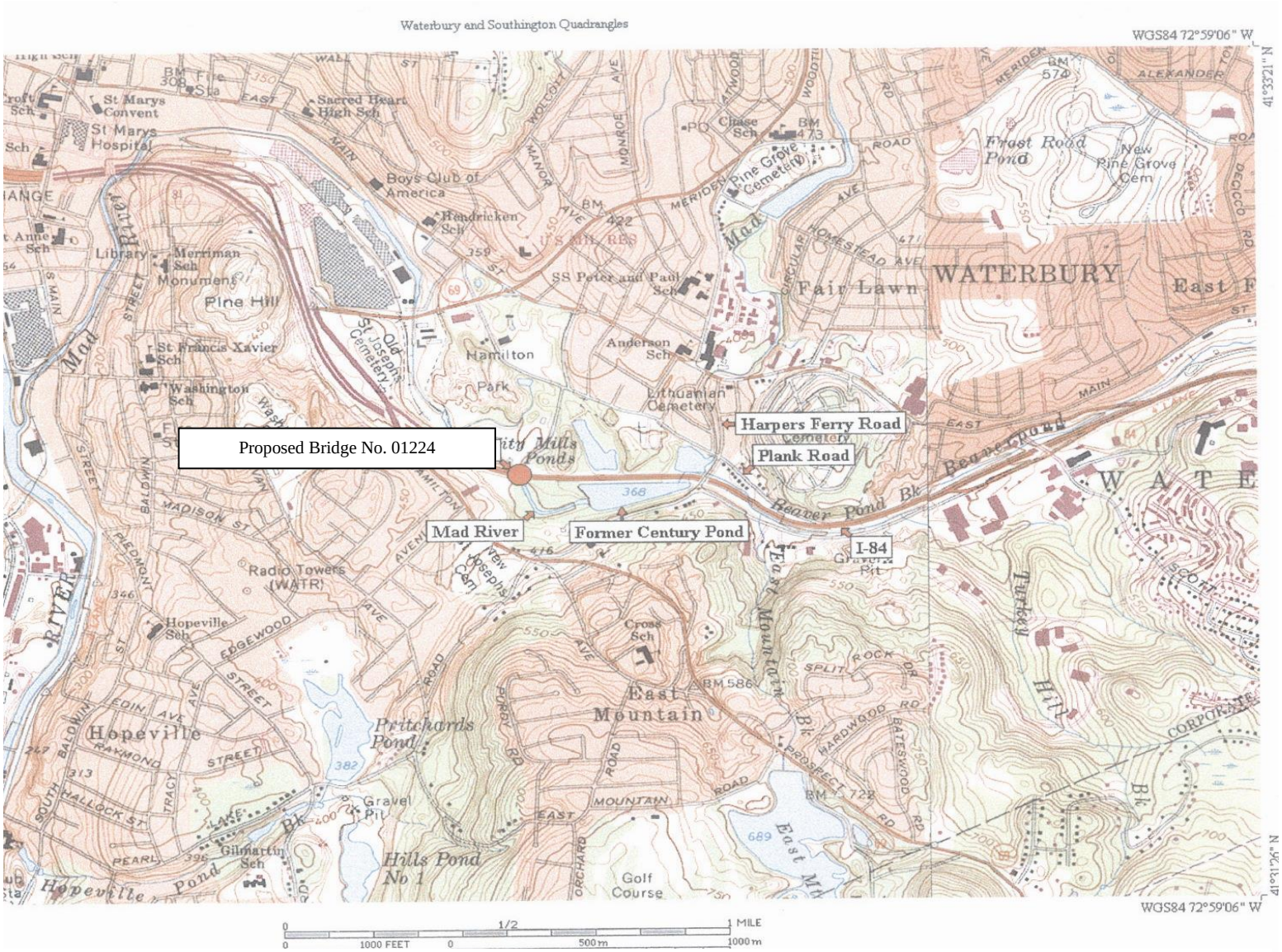
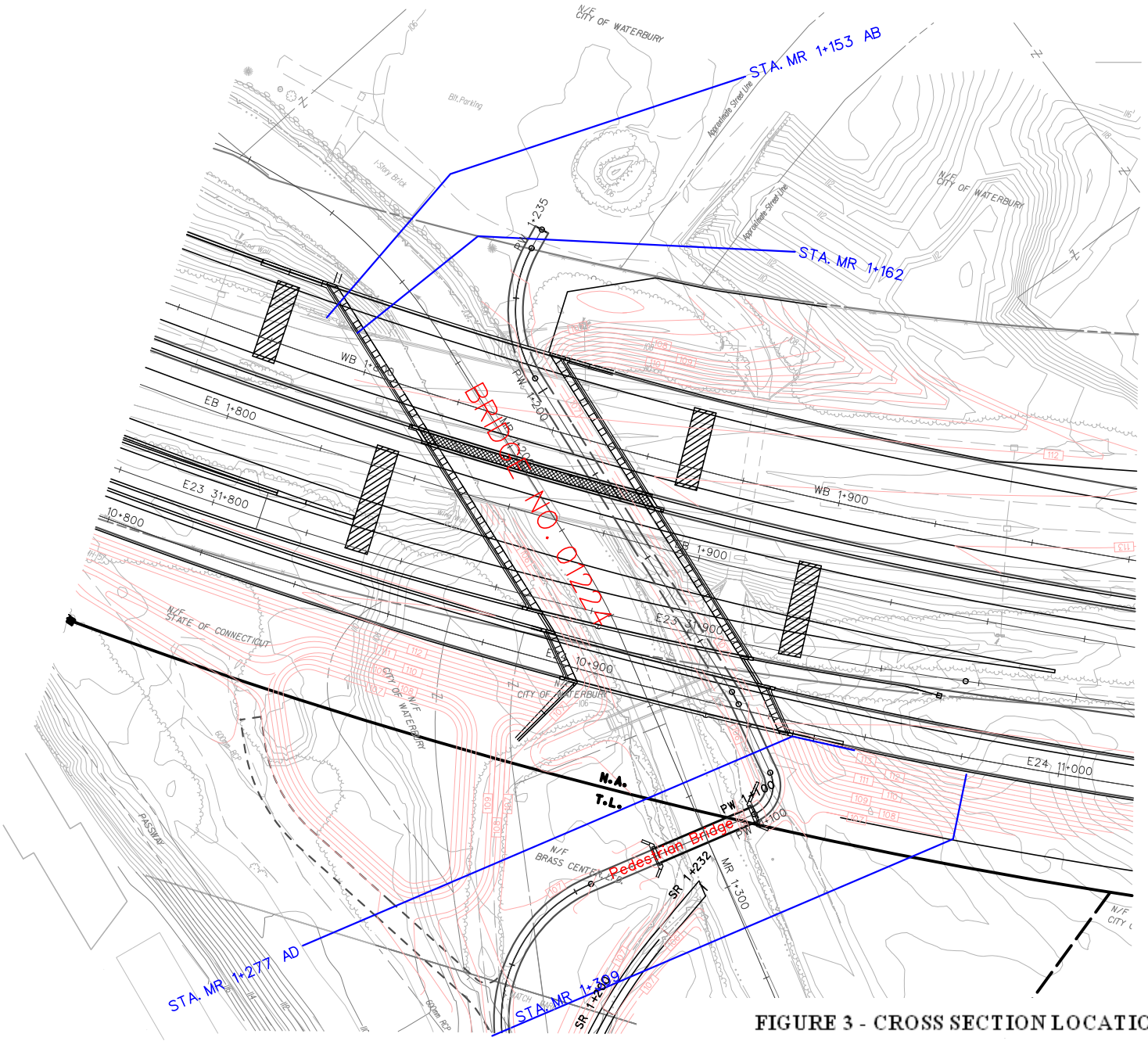


FIGURE 1 - PROJECT LOCATION PLAN



PROPOSED BRIDGE NO. 01224
OVER MAD RIVER

CROSS SECTION LOCATION PLAN

I-84 Waterbury
Project No. 151-273
(In State Plane Coordinate System)

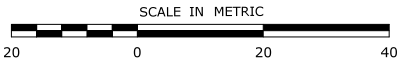


FIGURE 3 - CROSS SECTION LOCATION PLAN (VICINITY OF BRIDGE)

Report Background

This scour report with the accompanying final hydraulic report have been prepared as part of the final design for Bridge No. 01224, the westerly crossing of Interstate 84 over the Mad River. The proposed crossing will be in the same location as the existing bridge but due to its greater width will extend 42 meters (138 ft) further upstream.

Scour depths have been estimated following procedures set forth by the Federal Highway Administration in Hydraulic Engineering Circular No. 18 (HEC-18), *Estimating Scour at Bridges*, May 2001. As recommended on page 9.B-2 of the *2000 ConnDOT Drainage Manual*, the following Amended Local Abutment Scour Equation was utilized:

$$Y_s/Y_a = [2.27\ K_1\ K_2\ (L'/Y_a)^{0.43}\ Fr^{0.61}] + 0.05 \qquad \text{(ConnDOT)}$$

This equation predicts scour depths for the 50th percentile as compared to the more conservative HEC-18 version of Froehlich's equation (equation 7.1, page 7.8), which would have encompassed 98% of the laboratory produced scour holes from the original study. The HEC-18 version of Froehlich's equation is as follows:

$$Y_s/Y_a = [2.27\ K_1\ K_2\ (L'/Y_a)^{0.43}\ Fr^{0.61}] + 1 \qquad \text{(HEC-18)}$$

A comparison of the two local abutment equations shows that ConnDOT's version will predict scour depths $0.95Y_a$ less than proposed by HEC-18. Y_a is the average depth of floodplain flow at the upstream approach cross section.

The discharges used in this investigation have been approved by ConnDOT and are presented in the September 1999 *Hydrologic Report, Mad River, Waterbury, Connecticut* prepared by BLA (Ammann & Whitney). The discharges reported in the original 1979 and currently effective 2013 Waterbury Flood Insurance Studies are 25-30% lower than those approved by ConnDOT.

The hydraulic analysis completed for this investigation utilized HEC-RAS version 4.1.0 assuming mixed flow conditions. A CD containing the HEC-RAS data files is included in the referenced *Hydraulic Analysis for Design Report, Mad River*.

To avoid confusion between existing and proposed crossings in the report, the existing crossing is referred to as "Structure" followed by the ConnDOT bridge number, whereas the proposed crossing is called out as "Bridge" (e.g. existing Structure No. 01224 versus proposed Bridge No. 01224).

Proposed Bridge

Proposed Bridge No. 01224 will replace existing I-84 Structure No. 01224 over the Mad River. The new crossing will be a single span, welded steel plate girder bridge with spill-through type stub concrete abutments, eliminating the need for the existing center pier. The abutments will be founded on end bearing H-piles terminating in glaciofluvial deposits. The span of the bridge will be 29.2 meters (96 ft) measured between the abutment faces. The structure will be skewed approximately 60º to the watercourse; however, the abutments will be aligned with the Mad River's main channel.

The width of the crossing (measured along the river baseline) will be increased from the existing 40 meters (131 ft) to 91 meters (298 ft) to accommodate two additional lanes along the interstate and the realignments of the Eastbound Exit 23 On-Ramp and the Exit 25 Eastbound Off-Ramp. The widening will be accomplished on the upstream side of the crossing and will necessitate relocating the existing pedestrian bridge over the Mad River approximately 28 meters (92 ft) upstream of its present location. The pedestrian walkway will be moved to the easterly riverbank passing under the proposed I-84 bridge, instead of through an existing 3 m by 3 m (10 ft x 10 ft) concrete box culvert tunnel. This box tunnel will be abandoned. Refer to separate scour report for the Pedestrian Bridge Crossing.

Even with the wider bridge, it is anticipated that the constriction through the crossing will be lowered primarily due to the elimination of the existing in-water pier. The elimination will also reduce the scour potential, improve aquatic habitat and reduce the potential for debris clogs.

The hydraulic analyses indicate that, as the flow enters and transitions from upstream to downstream sides of the proposed bridge, the change in the water elevation as well as the velocity will be smaller compared to the existing condition due to less constriction. While the 100-year water surface elevation will drop approximately 0.74 m (2.43 ft; from the entrance to exit), the change in velocity will be 0.89 m/s (from 2.58 to 3.47 m/s). This produces the minimum superstructure underclearance of approximately 2.4 meters (7.9 ft) for the 100-year flow at the downstream face of the bridge. Compared to the existing condition, this elevation is 0.27 meter (0.9 ft) higher. The resulting downstream end velocity will be 0.91 m/s (3 ft/s) lower than the existing. For the 500-year discharge, the minimum underclearance will be approximately 2.1 meters (6.9 ft), again at the downstream side. The 500-year, entering and exiting flow velocities are 2.79 m/s (9.2 ft/s) and 4.72 m/s (15.5 ft/s) respectively.

The riverbanks under the existing Structure No. 01224 are protected by riprap larger than standard size gradation. The proposed design retains this riprap in front of the western abutment. On the eastern riverbank, it is also retained waterward of the pedestrian walkway proposed along the bank. Between the pedestrian walkway and the eastern abutment, concrete block slope protection will be installed for erosion protection. Due to the 42 meter (138 ft) upstream extension of the proposed crossing, the existing riprap protection must be extended upstream. The required size of this riprap was evaluated based on Hydraulic Engineering Circular No. 11 (HEC-11) methodology. These calculations indicate that Standard sized riprap will be adequate for not only the 100-year design, but also the 500-year check flow condition (see Appendix C).

Scour Potential Assessment and Results

Scour computations were completed for the 100-year Design and 500-year Check frequency discharges. The computations for the lower frequency discharges were not performed as the degree of contraction, velocity and other flow variables were found relatively moderate compared to the conditions under the above high frequency discharges.

The estimate of D_{50} was based on a soil sample of existing bed material taken in the vicinity of the proposed bridge (see Figure 4).

Figure 4. Soil Sample (For estimating D_{50} for Scour Analysis)

Scour analysis Soil Sample #1, upstream of I-84 Structure No. 01224, westerly riverbank, looking downstream, 12/7/00

Based on site inspections, it appears the existing streambed is relative stable with no signs of long-term scour except for the scour holes which have formed on both sides of the existing pier. As the pier will no longer be present in the post-project condition, it is assumed that the streambed will continually remain stable, and thus that the long-term channel scour will be insignificant.

Computed scour depths for the 100 and 500 year return frequencies are as follows:

Table 3. Summary of Computed Scour Depths

100 Year

	Scour Depths (m)			
	Long-Term	Contraction	Amended Local Abutment	Amended Total
Abutment 1 (Westerly)	0	0.76	2.73	3.49
Abutment 2 (Easterly)	0	0.76	0.31	1.07

500 Year

	Scour Depths (m)			
	Long-Term	Contraction	Amended Local Abutment	Amended Total
Abutment 1 (Westerly)	0	1.30	3.42	4.71
Abutment 2 (Easterly)	0	1.30	0.84	2.14

These results indicate that the Abutment 1 footing will be undermined, and the piles will be exposed in both the 100- and 500-year flow conditions.

The foundation of the bridge is designed to resist the estimated scour resulting from these high magnitude flood events.

Design Review for Scour and Conclusions

Footing

Page 2.4 of HEC-18 states:

> Placing the top of the footing or pile cap below the depth equal to the estimated long-term degradation and contraction scour depth will minimize obstruction to flood flows and resulting local scour.

The top of the footing has been located in accordance with this guideline for the 100-year design discharge. At the eastern abutment (#2), the top of the entire footing will be set at elevation 106.3 M. Likewise, the top elevation will also be set at 106.3 M for the upstream, southerly portion of the western abutment (#1). The downstream, northerly portion will be at elevation 104.7 M. The thickness of the footing will be 1.5 meters (4.9 ft; vertically).

Piles

The typical guideline for pile supported abutments is to design the substructure using normal factors of safety assuming the piles are unsupported to the depth of total scour (long-term plus contraction plus amended local abutment) for the design discharge.

The calculations indicate that the depth of amended total scour will not expose the piles at Abutment 2, the eastern abutment, for the 100-year design discharge. On the hand, for the Abutment 1, the western abutment, the piles will be exposed, as the computed total scour depth is 1.09 m (3.6 ft) below the bottom of the footing at the upstream end. The foundation was designed to withstand this potential scour condition using normal factors of safety.

"Superflood"

Page 2.4 of HEC-18 recommends that the foundation design should be checked for scour conditions resulting from a "Superflood". The design "should have a minimum factor of safety of 1.0 (ultimate load) under the superflood conditions."

For the proposed bridge the 500-year flood was assumed to be the "Superflood". Calculations indicate that the depth of amended total scour will expose the piles 2.31 meters (7.6 ft) at Abutment 1 while the bottom of the Abutment 2 footing will still be below the scour. The foundation design meets the requirement of a minimum factor of safety of 1.0 for this potential scour condition.

Revetment Design

Although the foundations have been designed to the computed total scour depth which is based on the fine particle size of the existing streambed material, the design also incorporates riprap revetment to further protect the bridge. As described earlier, the existing heavy (larger than Standard) riprap on the channel banks will remain under the bridge at the downstream end, while the upstream end, where widening of the bridge is proposed, will be provided with Standard Riprap revetment.

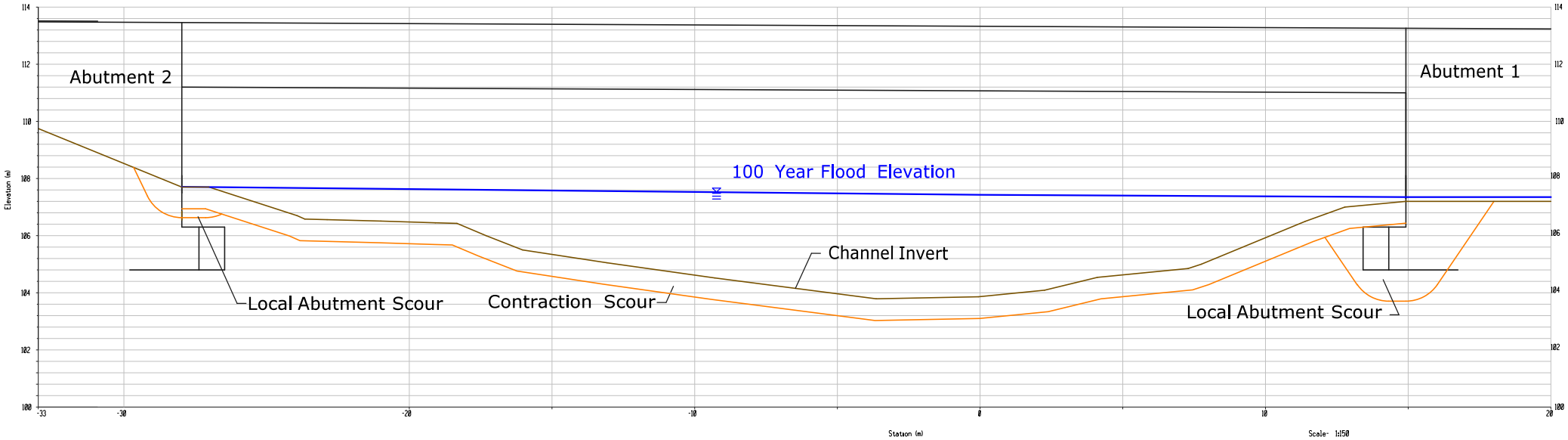
According to the HEC-11 calculations included in Appendix C, the final riprap revetment at and under the proposed bridge will be adequate up to the 500-year flow conditions. Beneath the Standard Riprap, a 150 mm-thick Granular Fill layer on geotextile will be provided to prevent loss of fines through the voids, as its requirement is demonstrated in the computations. Note that the Boring No. S4-3, Sample D1 was used to estimate the gradation of the native material in assessing the filter layer requirement. The soil sample used for the scour analysis was taken from a different location that is representative of the streambed material.

Typical details of the revetment design are included in Appendix A.

The channel stability analysis for other locations of the Mad River within the subject project limits is included in the referenced *Final River Relocation Report, Mad River & Beaver Pond Brook.*

Figure 5. Scour Depth Cross Sections

Proposed I-84 Bridge No. 01224, Section Along The Upstream Face (Looking Upstream), I-84 Waterbury Project 151-273, Mad River



Proposed I-84 Bridge No. 01224, Section Along The Upstream Face (Looking Upstream), I-84 Waterbury Project 151-273, Mad River

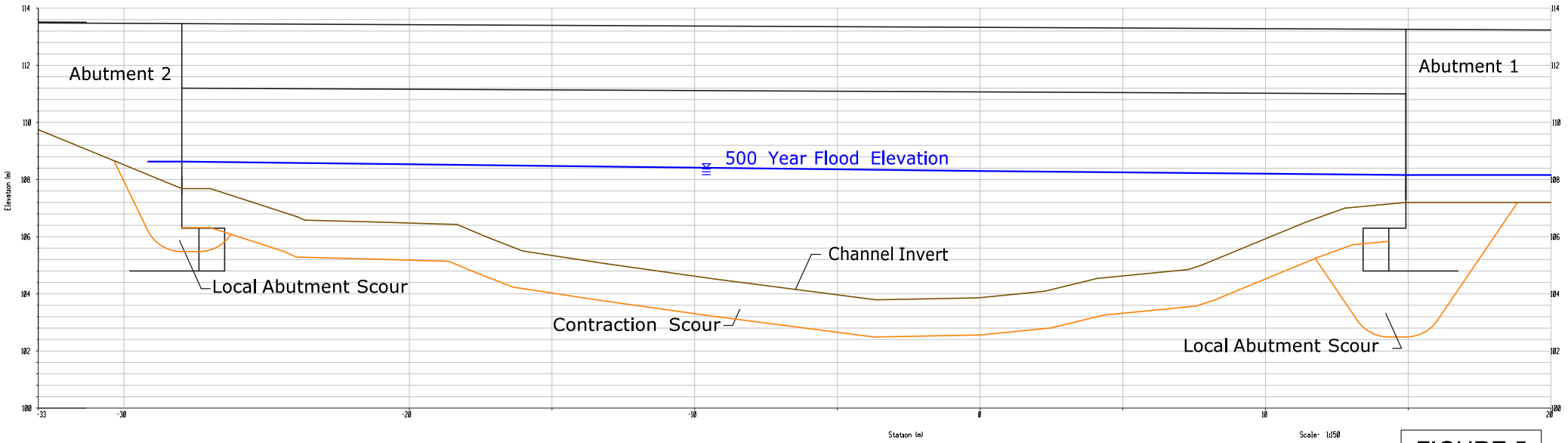
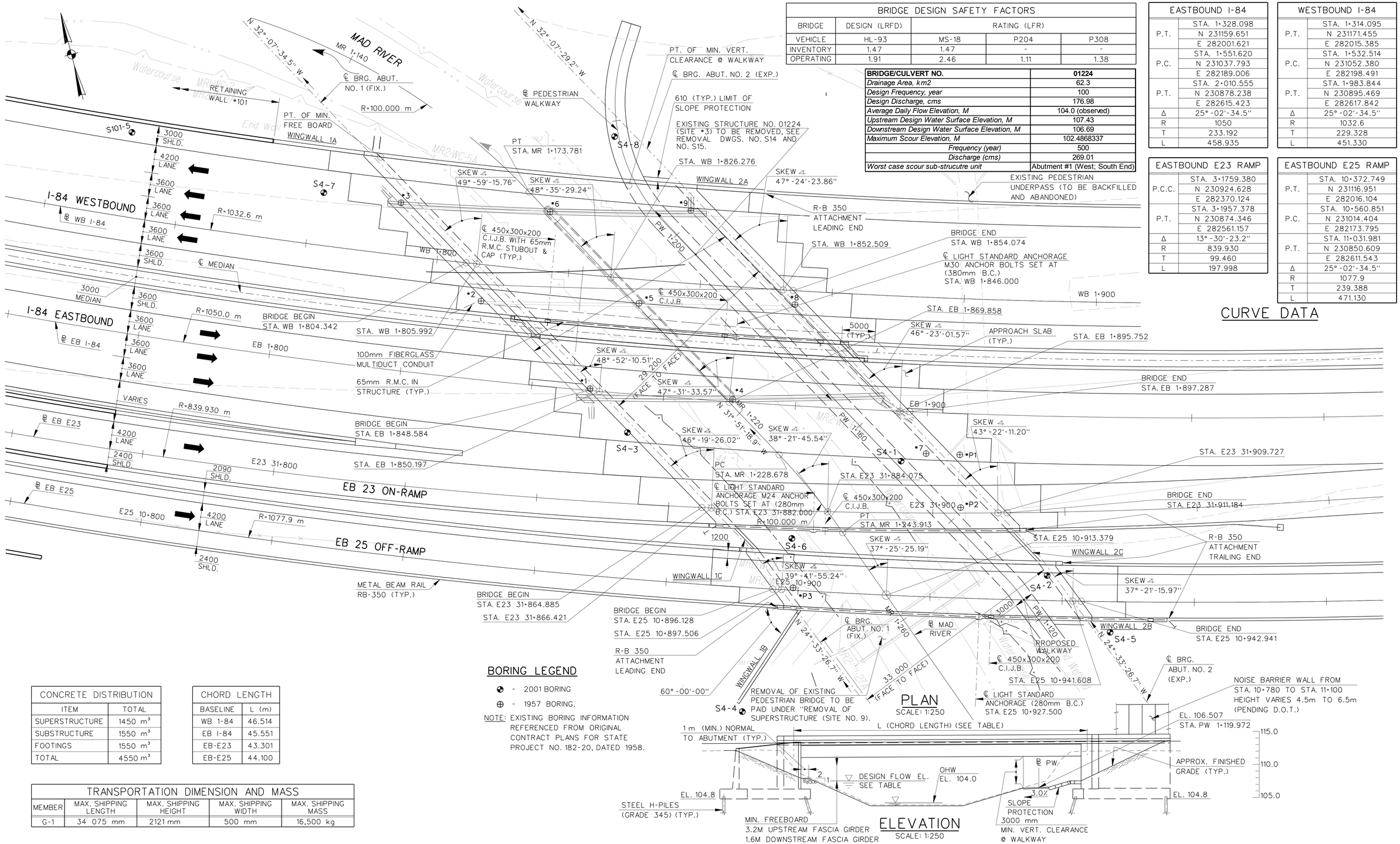


FIGURE 5

Appendix A: Structure Plans & Details

(Note: The plans and details included in this report are intended for information purposes only. If there are any discrepancies to the actual construction or "as-built" plans, the information reflected on the construction or "as-built" plans shall be construed more accurate.)



BRIDGE DESIGN SAFETY FACTORS				
BRIDGE	DESIGN (LRFD)	RATING (LFR)		
VEHICLE	HL-93	MS-18	P204	P308
INVENTORY	1.47	1.47	-	-
OPERATING	1.91	2.46	1.11	1.38

BRIDGE/CULVERT NO.	01224
Drainage Area, km2	62.3
Design Frequency, year	100
Design Discharge, cms	176.98
Average Daily Flow Elevation, M	104.0 (observed)
Upstream Design Water Surface Elevation, M	107.43
Downstream Design Water Surface Elevation, M	106.69
Maximum Scour Elevation, M	102.4868337
Frequency (year)	500
Discharge (cms)	269.01
Worst case scour sub-strucutre unit	Abutment #1 (West; South End)

EASTBOUND I-84	
P.T.	STA. 1+328.098
	N 231159.651
	E 282001.621
P.C.	STA. 1+551.620
	N 231037.793
	E 282189.006
P.T.	STA. 2+010.555
	N 230878.238
	E 282615.423
Δ	25°-02'-34.5"
R	1050
T	233.192
L	458.935

WESTBOUND I-84	
P.T.	STA. 1+314.095
	N 231171.455
	E 282015.385
P.C.	STA. 1+532.514
	N 231052.380
	E 282198.491
P.T.	STA. 1+983.844
	N 230895.469
	E 282617.842
Δ	25°-02'-34.5"
R	1032.6
T	229.328
L	451.330

EASTBOUND E23 RAMP	
P.C.C.	STA. 3+1759.380
	N 230924.628
	E 282370.124
P.T.	STA. 3+1957.378
	N 230874.346
	E 282561.157
Δ	13°-30'-23.2"
R	839.930
T	99.460
L	197.998

EASTBOUND E25 RAMP	
P.T.	STA. 10+372.749
	N 231116.951
	E 282016.104
P.C.	STA. 10+560.851
	N 231014.404
	E 282173.795
P.T.	STA. 11+031.981
	N 230850.609
	E 282611.543
Δ	25°-02'-34.5"
R	1077.9
T	239.388
L	471.130

CURVE DATA

BORING LEGEND

- 2001 BORING
- 1957 BORING.

NOTE: EXISTING BORING INFORMATION REFERENCED FROM ORIGINAL CONTRACT PLANS FOR STATE PROJECT NO. 182-20, DATED 1958.

CONCRETE DISTRIBUTION	
ITEM	TOTAL
SUPERSTRUCTURE	1450 m^3
SUBSTRUCTURE	1550 m^3
FOOTINGS	1550 m^3
TOTAL	4550 m^3

CHORD LENGTH	
BASELINE	L (m)
WB 1-84	46.514
EB 1-84	45.551
EB-E23	43.301
EB-E25	44.100

TRANSPORTATION DIMENSION AND MASS				
MEMBER	MAX. SHIPPING LENGTH	MAX. SHIPPING HEIGHT	MAX. SHIPPING WIDTH	MAX. SHIPPING MASS
G-1	34 075 mm	2121 mm	500 mm	16,500 kg

REV.	DATE	DESCRIPTION	SHEET. NO.
		REVISIONS	

SCALE AS NOTED

DESIGNER: G. JIANG
DRAFTER: M. MOSLEY
CHECKED BY: J. MUSKUS
DATE CHECKED: 12/2013

STATE OF CONNECTICUT
DEPARTMENT OF TRANSPORTATION

CADD ...\STR4\td\0273f04001.brg
PLOTTED 5/22/2014

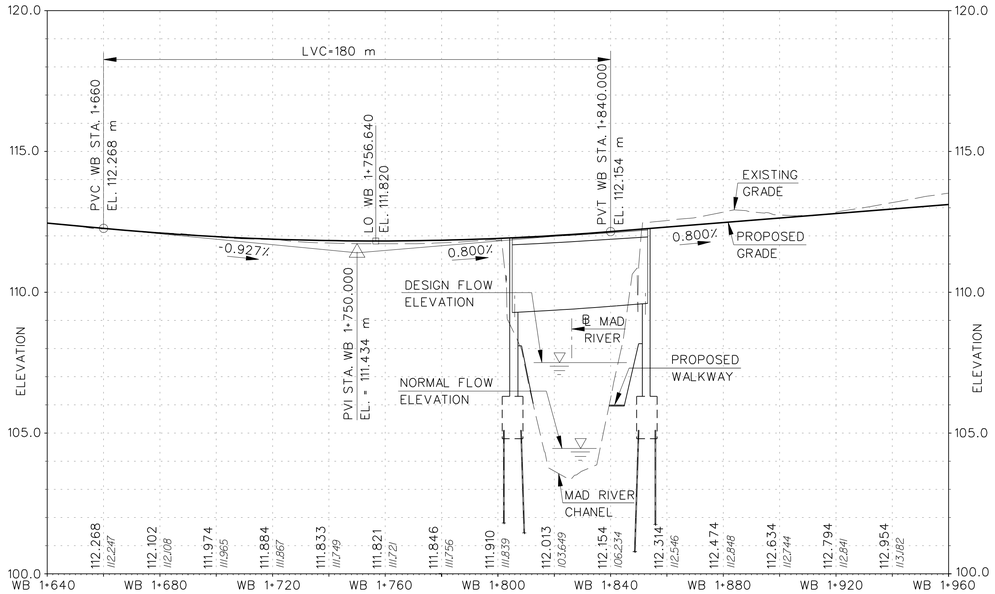
AMMANN & WHITNEY
2500 WESTCHESTER AVENUE
3RD FLOOR
HARRISON, NY

PROJECT TITLE:
RECONSTRUCTION OF I-84 WATERBURY
I-84 OVER MAD RIVER
STRUCTURE NO. 151-273-01224

TOWN: WATERBURY

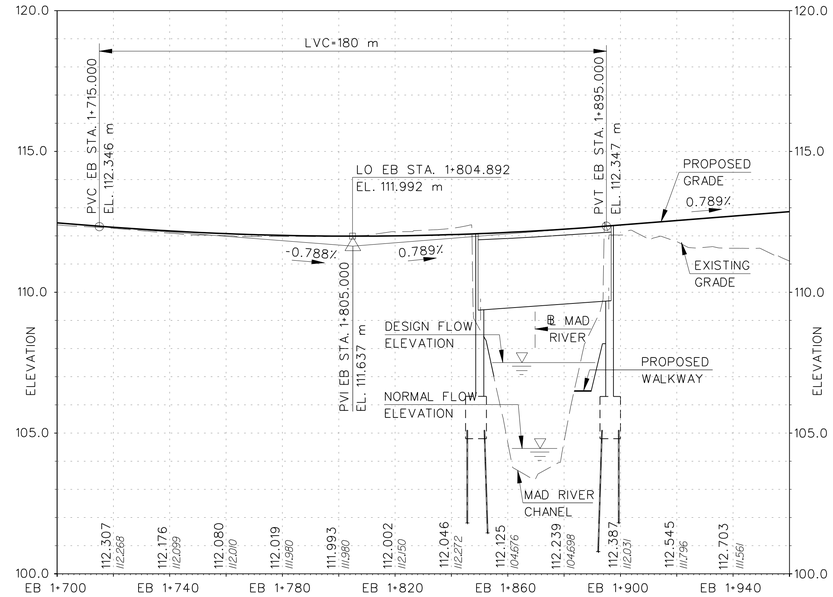
DRAWING TITLE: GENERAL PLAN & ELEVATION

PROJECT NO.: 151-273
DRAWING NO.: S1
SHEET NO.: 05.03.001



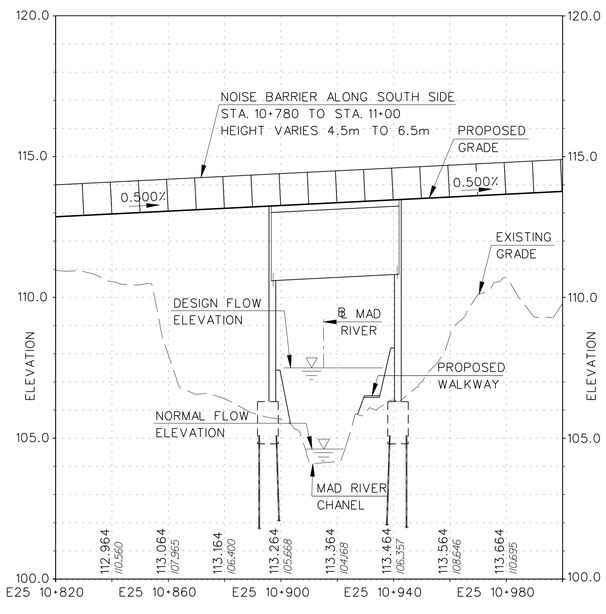
PROFILE I-84 WB OVER MAD RIVER

SCALE: HORIZ. 1:1000
VERT. 1:100



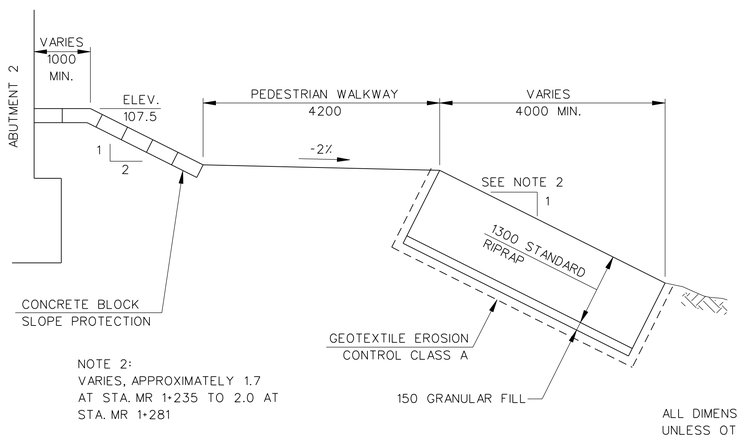
PROFILE I-84 EB OVER MAD RIVER

SCALE: HORIZ. 1:1000
VERT. 1:100



PROFILE EB 25 OFF-RAMP OVER MAD RIVER

SCALE: HORIZ. 1:1000
VERT. 1:100



NOTE 2:
VARIES, APPROXIMATELY 1.7
AT STA. MR 1+235 TO 2.0 AT
STA. MR 1+281

RIPRAP REVETMENT - ABUTMENT 2
STRUCTURE 151-273-01224
(LOOKING UPSTREAM)

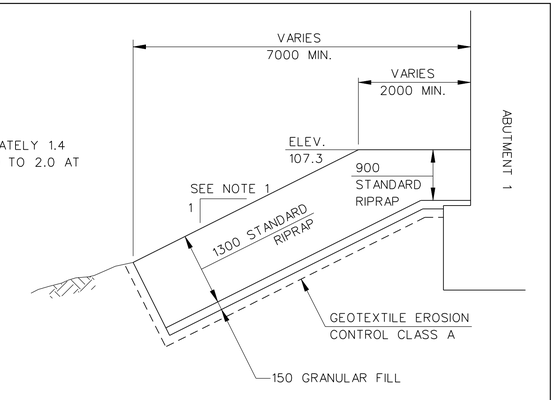
N.T.S.

ALL DIMENSIONS ARE SHOWN IN MILLIMETERS UNLESS OTHERWISE NOTED.

"TYP." IS AN ABBREVIATION FOR "TYPICAL" AND INDICATES THAT THE NOTED FEATURE SHALL BE APPLIED SIMSILARY ABOUT THE DETAIL.

ACCESS FOR STAGED REMOVAL OF EXISTING CENTER PIER WILL BE FROM THE EASTERLY ABUTMENT. DISTURBANCE OF EXISTING RIPRAPPED SLOPES SHALL BE MINIMIZED. COST OF RESTORATION OF RIPRAPPED SLOPES SHALL BE INCLUDED IN IN THE COST FOR "HANDLING WATER". REFER TO MISCELLANEOUS DETAILS.

NOTE 1:
VARIES, APPROXIMATELY 1.4
AT STA. MR 1+210 TO 2.0 AT
STA. MR 1+250



RIPRAP REVETMENT - ABUTMENT 1
STRUCTURE 151-273-01224
(LOOKING UPSTREAM)

N.T.S.

REV.	DATE	DESCRIPTION	SHEET. NO.
		REVISIONS	

SCALE AS NOTED

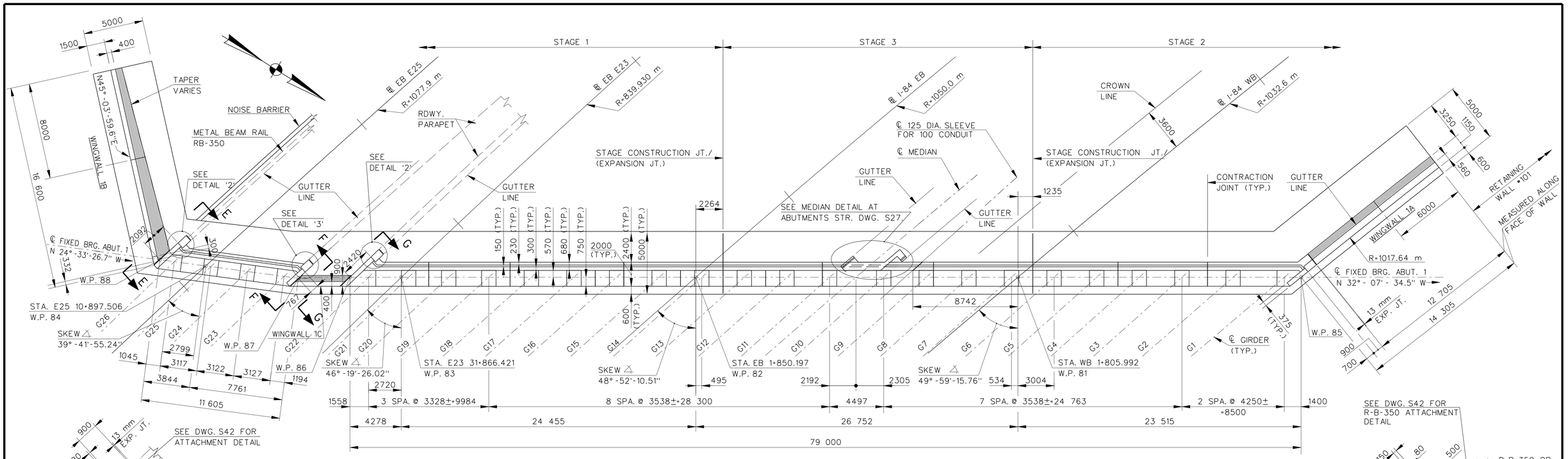
DESIGNER: G. JIANG
DRAFTER: M. MOSLEY
CHECKED BY: J. MUSKUS
DATE CHECKED:

PROJECT TITLE:
RECONSTRUCTION OF I-84 WATERBURY
I-84 OVER MAD RIVER
STRUCTURE NO. 151-273-01224

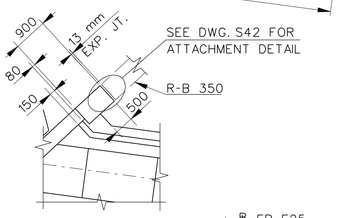
TOWN: WATERBURY

DRAWING TITLE:

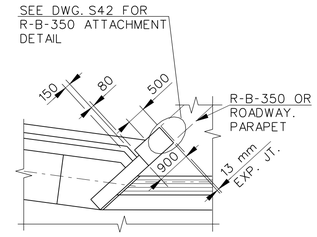
PROJECT NO.: 151-273
DRAWING NO.:
SHEET NO.:



PLAN



DETAIL '2'
SCALE: 1:75



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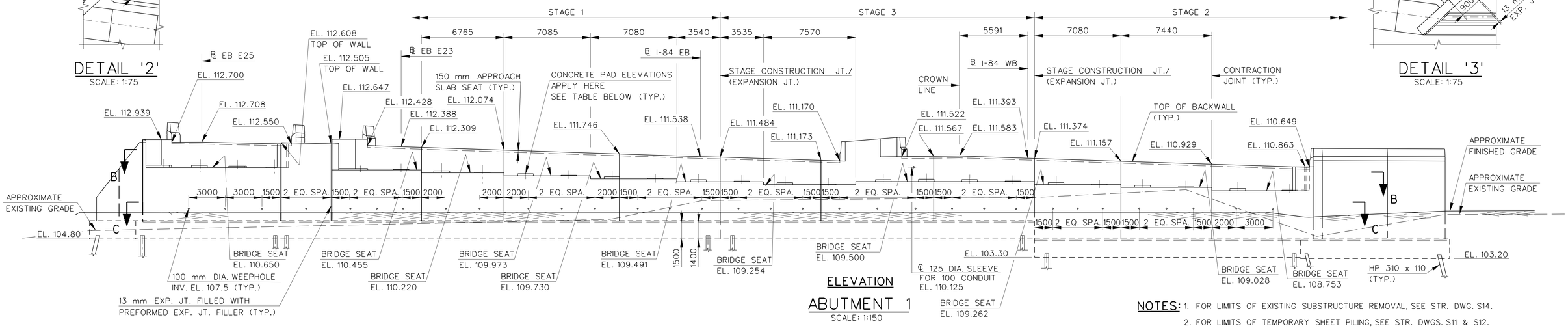


ELEVATION

ABUTMENT 1
SCALE: 1:150

NOTES:

1. FOR LIMITS OF EXISTING SUBSTRUCTURE REMOVAL, SEE STR. DWG. S14.
2. FOR LIMITS OF TEMPORARY SHEET PILING, SEE STR. DWGS. S11 & S12.
3. FOR WORKING POINT (W.P.) COORDINATES, SEE STR. DWG. S3.
4. FOR WINGWALL ELEVATIONS, SEE STR. DWG. S25.
5. FOR CONCRETE PAD DETAILS, SEE STR. DWG. S23.
6. FOR ABUTMENT TYPICAL SECTION, SEE STR. DWG. S22
7. FOR SECTIONS "E-E", "F-F" AND "G-G", SEE STR. DWG. S24.
8. FOR SECTIONS "B-B" AND "C-C", SEE STR. DWG. S20.
9. FOR PILE LAYOUT, SEE STR. DWG. S17.

CONCRETE PAD ELEVATIONS

	WESTBOUND										EASTBOUND AND EB 23 ON-RAMP												EB 24 OFF-RAMP			
GIRDER	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G12	G13	G14	G15	G16	G17	G18	G19	G20	G21	G22	G23	G24	G25	G26
ELEVATION	108.803	108.940	109.078	109.195	109.312	109.431	109.550	109.670	109.700	109.662	109.304	109.422	109.541	109.660	109.780	109.901	110.023	110.146	110.270	110.387	110.505	110.576	110.699	110.769	110.839	110.847

REV.	DATE	DESCRIPTION	SHEET. NO.
		REVISIONS	

SCALE AS NOTED

DESIGNER: G. JIANG
DRAFTER: M. MOSLEY
CHECKED BY: J. MUSKUS
DATE CHECKED: 12/2013

STATE OF CONNECTICUT
DEPARTMENT OF TRANSPORTATION

CADD ...\str4\fd\0273F04018.BRG
PLOTTED 4/2/2014

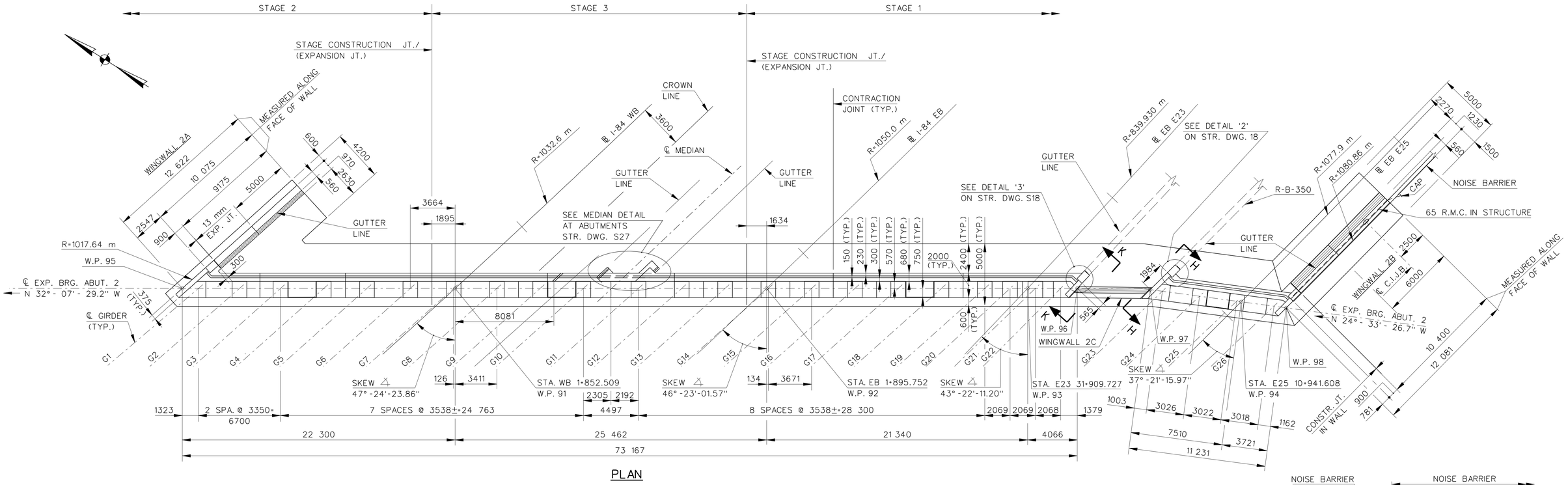
AMMANN & WHITNEY
2500 WESTCHESTER AVENUE
3RD FLOOR
HARRISON, NY

PROJECT TITLE:
RECONSTRUCTION OF I-84 WATERBURY
I-84 OVER MAD RIVER
STRUCTURE NO. 151-273-01224

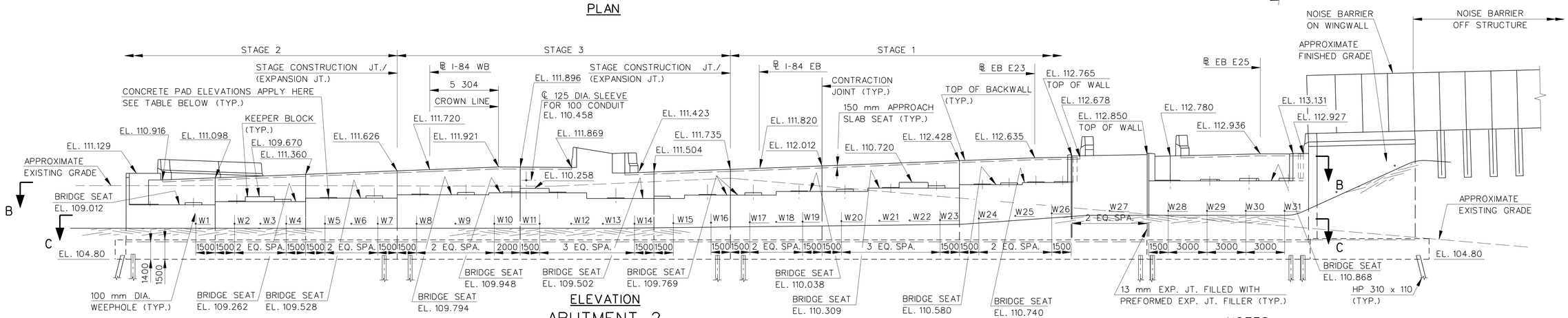
TOWN: WATERBURY

DRAWING TITLE: ABUTMENT 1 – PLAN AND ELEVATION

PROJECT NO.: 151-273
DRAWING NO.: S18
SHEET NO.: 05.03.018



PLAN



ELEVATION

ABUTMENT 2

SCALE: 1:150

NOTES:

1. FOR LIMITS OF EXISTING SUBSTRUCTURE REMOVAL, SEE STR. DWG. S14.
2. FOR LIMITS OF TEMPORARY SHEET PILING, SEE STR. DWGS. S11 & S12.
3. FOR WORKING POINT (W.P.) COORDINATES, SEE STR. DWG. S3.
4. FOR WINGWALL ELEVATIONS, SEE STR. DWG. S25.
5. FOR CONCRETE PAD AND KEEPER BLOCK DETAILS, SEE STR. DWG. S23.
6. FOR TYPICAL SECTION, SEE STR. DWG. S22
7. FOR SECTIONS "H-H" AND "K-K", SEE STR. DWG. S24.
8. FOR SECTIONS "B-B" AND "C-C", SEE STR. DWG. S21.
9. FOR PILE LAYOUT, SEE STR. DWG. S17.

CONCRETE PAD ELEVATIONS

WESTBOUND										EASTBOUND AND EB 23 ON-RAMP												EB 25 OFF-RAMP			
GIRDER	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G12	G13	G14	G15	G16	G17	G18	G19	G20	G21	G22	G23	G24	G25	G26
ELEVATION	109.062	109.187	109.312	109.445	109.578	109.711	109.844	109.977	110.033	109.998	109.552	109.685	109.819	109.953	110.088	110.224	110.359	110.495	110.630	110.710	110.790	110.816	110.918	110.987	111.057	111.071

WEEPHOLE INVERT ELEVATION

WEEPHOLE NO.	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16	W17	W18	W19	W20	W21	W22	W23	W24	W25	W26	W27	W28	W29	W30	W31
INV. EL.	107.500	107.500	107.500	107.500	107.500	107.500	107.500	107.500	107.500	107.500	107.500	107.500	107.500	107.500	107.500	107.500	107.500	107.500	107.500	107.500	107.500	107.500	107.500	107.500	107.500	107.500	107.500	107.500	107.500	107.500	107.500

REV.	DATE	DESCRIPTION	SHEET. NO.
		REVISIONS	

SCALE AS NOTED

DESIGNER: G. JIANG
DRAFTER: M. MOSLEY
CHECKED BY: J. MUSKUS
DATE CHECKED: 12/2013

STATE OF CONNECTICUT
DEPARTMENT OF TRANSPORTATION

CADD ...\str4\fd\0273F04019.BRG
PLOTTED 4/2/2014

AMMANN & WHITNEY
2500 WESTCHESTER AVENUE
3RD FLOOR
HARRISON, NY

PROJECT TITLE:
RECONSTRUCTION OF I-84 WATERBURY
I-84 OVER MAD RIVER
STRUCTURE NO. 151-273-01224

TOWN: WATERBURY

DRAWING TITLE: ABUTMENT 2 – PLAN AND ELEVATION

PROJECT NO.: 151-273
DRAWING NO.: S19
SHEET NO.: 05.03.019

Appendix B: Scour Computations

Based on DOT Design Discharges

- Summary Sheet
- 100-YR Contraction Scour
- 100-YR Abutment Scour
- 500-YR Contraction Scour
- 500-YR Abutment Scour
- Soil Sample Analysis (Sample #1, bed material)

Final Design

Bridge No. 01224
Westerly I-84 Crossing over the Mad River
Computed Scour Depths using Froehlich's Abutment Scour Equation
July 2006 - Revised March 2014

Abutment #1- Westerly Abutment or Right Abutment Looking Upstream

Flood Recurrence	Ave. Flow Depth Obstructed	Scour Depth (m)				
		Long-Term	Contraction	Abutment Equation	Amended Abutment	Amended Total
Q_{100}	1.18	0.0	0.76	Froehlich	2.73	3.49
Q_{500}	2.19	0.0	1.30	Froehlich	3.42	4.71
Overtopping	> Q_{500}					

Abutment #2- Easterly Abutment or Left Abutment Looking Upstream

Flood Recurrence	Ave. Flow Depth Obstructed	Scour Depth (m)				
		Long-Term	Contraction	Abutment Equation	Amended Abutment	Amended Total
Q_{100}	0.57	0.0	0.76	Froehlich	0.31	1.07
Q_{500}	0.58	0.0	1.30	Froehlich	0.84	2.14
Overtopping	> Q_{500}					

Comparison of Footing Elevations to Computed Scour Depths

Abutment No.	Depth of Footing (m)	Elevation (m)		Assumed Ground Elevation at Base of Abutment	Elevation of Scour at Abutment (m)			
					100 Year Discharge		500 Year Discharge	
		Top of Footing	Bottom of Footing		Long-Term + Contraction	Total	Long-Term + Contraction	Total
1 (U/S)	1.5	106.3	104.8	107.20	106.44	103.71	105.90	102.49
1 (D/S)	1.5	104.8	103.3	106.00	105.24	102.51	104.70	101.29
2	1.5	106.3	104.8	107.70	106.94	106.63	106.40	105.56

Abutment No. 1

-Top of footing below the sum of long-term channel degradation and contraction scour depths for the 100 year discharge- Design OK

-Computed total scour depth for the 100 year discharge is below the bottom of the footing, design the foundation assuming the piles are unsupported to the depth of total scour

-Computed total scour depth for the 500 year discharge is below the bottom of the footing, check the design for FS = 1.0 assuming the piles are unsupported to the depth of total scour

Abutment No. 2

-Top of footing below the sum of long-term channel degradation and contraction scour depths for the 100 year discharge- Design OK

-Computed total scour depth for the 100 year discharge is above the bottom of the footing, piles are not exposed by scour

-Computed total scour depth for the 500 year discharge is above the bottom of the footing, piles are not exposed by scour

PROJECT NO. 151-273 **BRIDGE NO.** 01224 (Prop.) **UNIT:** Metric

Ref. HEC-18., May 2001 (4th ed.)

(October 2013 Note: These equation are still valid in HEC-18, 5th ed.)

SUMMARY

Contraction Scour		Type:	**LIVE-BED**	Depth:	**0.76** m	Event:	**100-YR**
Local	**East Abut. #2**	**LEFT**	Eq.: Froehlich	Depth:	**0.31** m	Event:	**100-YR**
Abutment	**West Abut. #1**	**RIGHT**	Eq.: Froehlich	Depth:	**2.73** m	Event:	**100-YR**

CONTRACTION SCOUR

$Vc = Ku\ y^{1/6}\ D^{1/3}$ ……Eq. 5.1

= **2.07** ***m/s*** Critacal velocity above which bed material of size D and smaller will be transported

Ku = 6.19 m (6.19 in SI units; 11.17 in English units)

y = 2.43 m Average depth of flow upstream of the bridge

D = 0.024 m Particle size for Vc *, m* (use D_{50})

V1 = **2.58** ***m/s*** The mean velocity of the flow in the main channel or overbank area upstream of the brige opening

Vc < V1 ***Thus, LIVE-BED CONTRACTION SCOUR***

Live-Bed Contraction Scour ==========

$Y_2/Y_1 = (Q_2/Q_1)^{6/7}\ (W_1/W_2)^{k_1}$ = **1.22** ……Eq. 5.2

$Y_s = Y_2 - Y_o$ **m** ……Eq. 5.3

= **0.76 m** Average contraction scour depth

Y_1 = 2.43 m Average depth in the upstream main channel

Y_2 = 2.96 m Average depth in the contracted section

Y_o = 2.20 m Existing depth in the contracted section before scour

Q_1 = 151.32 m3/s Flow in the upstream channel transporting sediment

Q_2 = 176.98 m3/s Flow in the contracted channel

W_1 = 34.74 m Bottom width of the upstream main channel that is transporting bed material

W_2 = 31.19 m Bottom width of the main channel in the contracted section less pier width

k_1 = 0.59 Exponent determined below (V^*/ω = 0.44)

V^* = 0.2802 $=(T_o/\rho)^{1/2}$ or $(gY1\ S1)^{1/2}$, shear velocity in the upstream section , m/s

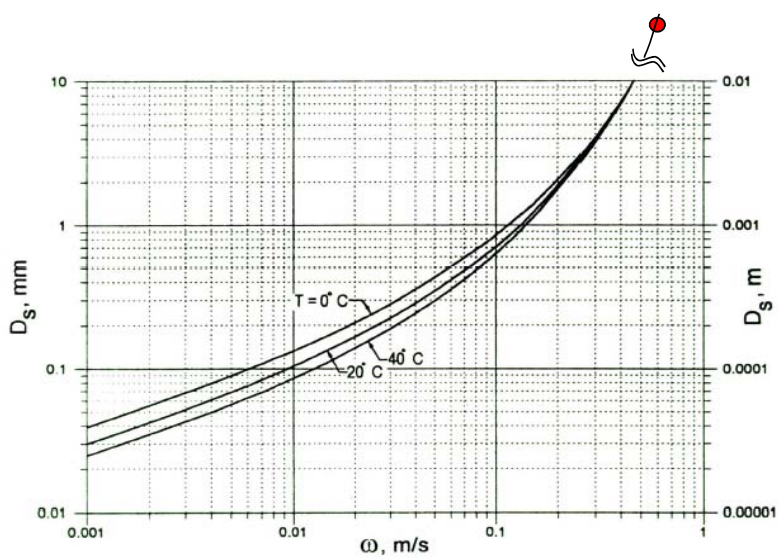
ω = 0.63 m/s Fall velocity of bed material based on the D_{50} (Figure 5.8)

g = 9.81 m/s^2 Acceleration of gravity

S1 = 0.003114 m/m Slope of energy gradeline of main channel

T_o = 78.54 Pa (N/m^2) Shear stess on the bed

ρ = 1000 kg/m^3 Density of water



V/ω*	*k1*	*Mode of Bed Material Transport*
<0.50	0.59	Mostly contact bed material discharge
0.50 to 2.0	0.64	Some suspended bed material discharge
>2.0	0.69	Mostly suspended bed material discharge

Figure 5.8. Fall velocity of sand-sized particles with specific gravity of 2.65 in metric units.

Clear-Water Contraction Scour ==========

$$y_2 = \left[\frac{K_u Q^2}{D_m^{2/3} W^2} \right]^{3/7}$$ .....Eq. 5.4

$y_s = y_2 - y_o$ **m** .....Eq. 5.5

=	**N/A**	**m**	Average contraction scour depth	**LIVE-BED controls. Ignore this procedure**
y_2 =	2.48	m	Average equilibrium depth in the contracted section after contraction scour	
y_o =	2.20	m	Average existing depth in the contracted section	
Q =	176.98	m3/s	Discharge through the bridge or on the set-back overbank area at the bridge associated with the width W	
W =	31.19	m	Bottom width of the contracted section less pier widths	
K_u =	0.0250		(0.025 in SI units; 0.0077 in English units)	
D_m =	0.0300	m	Diameter of the smallest nontransportable particle in the bed material (1.25 D50) in th contacted setion	
D_{50} =	0.0240	m	Median diameter of bed material	

Because D_{50} is not the largest particle in the bed material, the scoured section can be slightly armored. Therefore, the D_m is assumed to be 1.25 D_{50}. For stratified bed material the depth of scour can be determined by using the clear-water scour equation sequentially with successive D_m of the bed material layers.

Data Source

Eq. 5.1			From:	RS
y =	2.43	m	D	1277
V1 =	2.58	m	T	1214.5 BR U

Eq. 5.2 & 5.3				
Y1 =	2.43	m	D	1277
Yo =	2.20	m	T	1214.5 BR U
Q1 =	151.32	m3/s	D	1277
Q2 =	176.98	m3/s	T	1214.5 BR U
W1 =	34.74	m	D	1277
or	(n/a)	m (manual)		
W2 =	31.19	m	T	1214.5 BR U
or	(n/a)	m (manual)		
S1 =	0.003114	m/m	C	1277
To =	78.54	Pa (N/m^2)	C	1214.5 BR U
P2 =	0	m (pier width)		

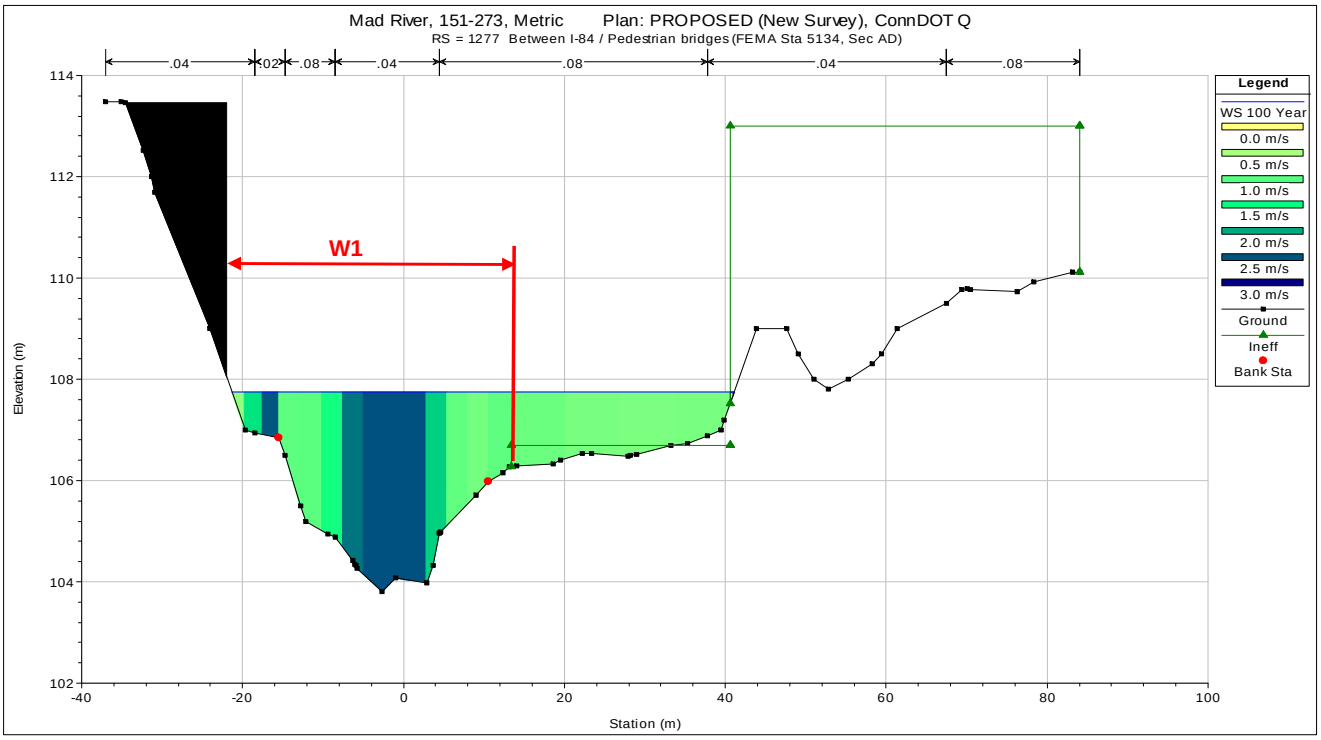
Eq. 5.4 & 5.5				
Q =	176.98	m3/s	C	1214.5

Legends:

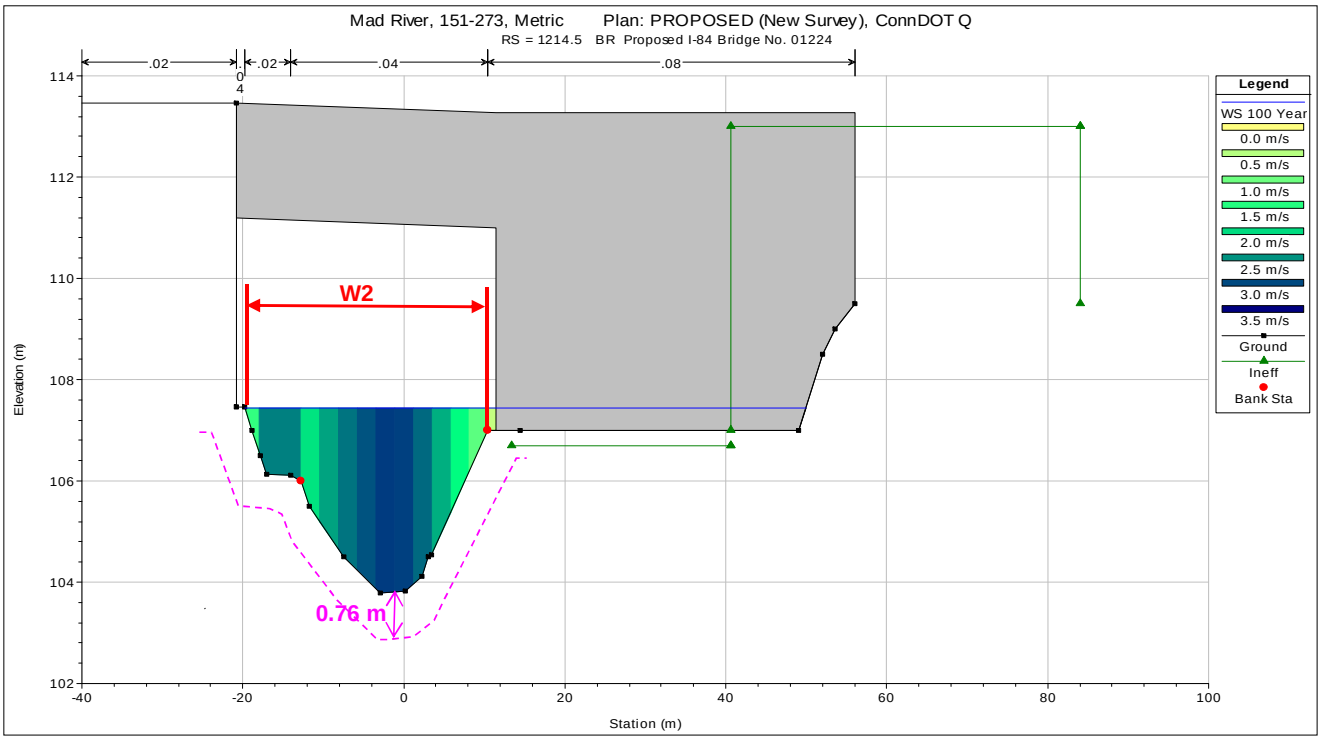
T	based on the flow data for the entire section
C	data from "Channel" column in the HEC-RAS Cross Section Output
D	from evaluting Flow Distribtion Output and resetting "Channel" and "Overbank" limits
M	manual data entry

Cross Sections used for Contraction Scour Computations

UPSTREAM SECTION 1277



CONTRACTED SECTION 1214.5 BR U



**This drawing is intended to provide as a basic, rough visualization of the scour depth. See Figure 5 for more accurate depiction.*

UPSTREAM CHANNEL SECTION

River Station 1277 Event: 100-YR

HEC-RAS CROSS SECTION OUTPUT

Plan: PR_DOT Mad River Reach 1 RS: 1277 Profile: 100 Year

E.G. Elev (m)	107.89	Element	Left OB	Channel	Right OB	Total
Vel Head (m)	0.15	Wt. n-Val.	0.024	0.06	0.077	
W.S. Elev (m)	107.74	Reach Len. (m)	18.58	18.58	18.58	
Crit W.S. (m)	106.52	Flow Area (m2)	4.12	75.68	36.23	
E.G. Slope (m/m)	0.003114	Area (m2)	4.12	75.68	36.28	116.08
Q Total (m3/s)	176.98	Flow (m3/s)	7.78	139.25	29.95	
Top Width (m)	62.43	Top Width (m)	5.89	26.06	30.47	
Vel Total (m/s)	1.53	Avg. Vel. (m/s)	1.89	1.84	0.83	
Max Chl Dpth (m)	3.93	Hydr. Depth (m)	0.7	2.9	1.21	1.86
Conv. Total (m3/s)	3171.7	Conv. (m3/s)	139.5	2495.6	536.7	
Length Wtd. (m)	18.58	Wetted Per. (m)	6.06	26.98	30.14	
Min Ch El (m)	103.81	Shear (N/m2)	20.79	85.65	36.7	
Alpha	1.26	Stream Power (N/m s)	4022.22	0	0	
Frctn Loss (m)	0.06	Cum Volume (1000 m3)	3.53	27.13	0.49	
C & E Loss (m)	0.06	Cum SA (1000 m2)	14.34	11.49	1.25	

	Flow dis.	*manual*
Left WS Sta.	-21.92	-21.34
Left Convy Sta.		-21.34
Left Main Channel	-21.34	
Right Main Channel	13.4	
Right Convy Sta.	47.83	
Right WS Sta.	47.83	41.08
L' (left) 0	L (left)	0
L' (Right) 34.43	L (Right)	27.68

HEC-RAS FLOW DISTRIBUTION IN CROSS SECTION OUTPUT

	W1	Q1, Qe	Area	Y1	V1
LEFT					
Main	34.74	151.32	84.34	2.43	1.80
Right		25.66	31.76		

Plan: PR_DOT Mad River Reach 1 RS: 1277 Profile: 100 Year

	Pos	Left Sta (m)	Right Sta (m)	Flow (m3/s)	Area (m2)	W.P. (m)	Percent Conv	Hydr Depth(m)	Velocity (m/s)	Shear (N/m2)	Power (N/m s)
1	LOB	-21.92	-19.76	0.37	0.57	1.74	0.21	0.36	0.65	9.97	
2	LOB	-19.76	-17.61	2.81	1.7	2.16	1.59	0.79	1.65	24.01	
3	LOB	-17.61	-15.45	4.6	1.86	2.16	2.6	0.86	2.48	26.29	
4	Chan	-15.45	-12.84	3.82	4.03	2.91	2.16	1.55	0.95	42.2	
5	Chan	-12.84	-10.24	6.43	6.68	2.69	3.63	2.56	0.96	75.66	
6	Chan	-10.24	-7.63	10.35	7.41	2.63	5.85	2.84	1.4	86.03	
7	Chan	-7.63	-5.03	20.02	8.67	2.66	11.31	3.33	2.31	99.37	
8	Chan	-5.03	-2.42	24.86	9.83	2.63	14.05	3.77	2.53	113.94	
9	Chan	-2.42	0.19	24.61	9.76	2.62	13.91	3.74	2.52	113.52	
10	Chan	0.19	2.79	24.52	9.71	2.61	13.85	3.72	2.53	113.69	
11	Chan	2.79	5.4	14.56	8.19	2.93	8.23	3.14	1.78	85.38	
12	Chan	5.4	8	5.86	6.27	2.64	3.31	2.41	0.94	72.46	
13	Chan	8	10.61	4.22	5.14	2.64	2.38	1.97	0.82	59.49	
14	ROB	10.61	13.4	4.29	4.52	2.81	2.42	1.62	0.95	49.2	
15	ROB	13.4	20.2	8.44	9.67	6.8	4.77	1.42	0.87	43.4	
16	ROB	20.2	27	6.64	8.38	6.8	3.75	1.23	0.79	37.6	
17	ROB	27	33.8	6.02	7.9	6.8	3.4	1.16	0.76	35.45	
18	ROB	33.8	40.6	4.56	5.76	6.92	2.58	0.85	0.79	25.39	
19	ROB	40.6	47.83	0	0.05	0.53	0	0.11	0	3.02	
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CONTRACTED CHANNEL SECTION

River Station 1214.5 BR U

CROSS SECTION OUTPUT

Plan: PR_DOT Mad River Reach 1 RS: 1214.5 BR U Profile: 100 Year

E.G. Elev (m)	107.78	Element	Left OB	Channel	Right OB	Total
Vel Head (m)	0.34	Wt. n-Val.	0.023	0.04	0.08	
W.S. Elev (m)	107.43	Reach Len. (m)	89.02	89.02	89.02	
Crit W.S. (m)	106.64	Flow Area (m2)	7.54	60.53	0.43	
E.G. Slope (m/m)	0.003173	Area (m2)	7.54	60.53	0.43	68.5
Q Total (m3/s)	176.98	Flow (m3/s)	18.77	158.03	0.17	
Top Width (m)	31.19	Top Width (m)	7.01	23.18	1	
Vel Total (m/s)	2.58	Avg. Vel. (m/s)	2.49	2.61	0.4	
Max Chl Dpth (m)	3.64	Hydr. Depth (m)	1.08	2.61	0.43	2.20
Conv. Total (m3/s)	3141.7	Conv. (m3/s)	333.3	2805.4	3.1	
Length Wtd. (m)	89.02	Wetted Per. (m)	7.31	23.98	1	
Min Ch El (m)	103.79	Shear (N/m2)	32.06	78.54	13.47	
Alpha	1.01	Stream Power (N/m s)	2681.16	0	0	
Frctn Loss (m)	0.39	Cum Volume (1000 m3)	3.43	25.86	0.15	
C & E Loss (m)	0.08	Cum SA (1000 m2)	14.22	11.03	0.96	

	Flow dis.	*manual*
Left WS Sta.		-20.8
Left Flood Sta.		-20.8
Left Main Channel	-19.81	
Right Main Channel	10.46	
Right Flood Sta.		11.46
Right WS Sta.		11.46
L' (left) 0.9944	L (left)	0.9944
L' (Right) 1	L (Right)	1

FLOW DISTRIBUTION IN CROSS SECTION OUTPUT

	W1	Q1, Qe	Area	Y1	V1
LEFT		0.72	0.512		
Main	30.2656	176.08	67.558	2.23	2.61
Right		0.17	0.43		

Plan: PR_DOT Mad River Reach 1 RS: 1214.5 BR U Profile: 100 Year

	Pos	Left Sta (m)	Right Sta (m)	Flow (m3/s)	Area (m2)	W.P. (m)	Percent Conv	Hydr Depth(m)	Velocity (m/s)	Shear (N/m2)	Power (N/m s)
1	LOB	-23.14	-17.93	1.12	0.8	2	0.63	0.44	1.41	12.37	
2	LOB	-17.93	-12.72	17.65	6.74	5.31	9.98	1.29	2.62	39.48	
3	Chan	-12.72	-10.4	8.57	4.42	2.47	4.84	1.91	1.94	55.74	
4	Chan	-10.4	-8.08	13.82	5.81	2.38	7.81	2.5	2.38	75.91	
5	Chan	-8.08	-5.77	18.8	6.95	2.36	10.63	3	2.7	91.84	
6	Chan	-5.77	-3.45	22.92	7.82	2.35	12.95	3.37	2.93	103.67	
7	Chan	-3.45	-1.13	25.96	8.39	2.32	14.67	3.62	3.09	112.36	
8	Chan	-1.13	1.19	25.36	8.28	2.33	14.33	3.57	3.06	110.7	
9	Chan	1.19	3.51	20.6	7.42	2.41	11.64	3.2	2.78	95.6	
10	Chan	3.51	5.82	13.09	5.69	2.45	7.4	2.45	2.3	72.11	
11	Chan	5.82	8.14	6.73	3.81	2.45	3.8	1.65	1.76	48.35	
12	Chan	8.14	10.46	2.18	1.94	2.45	1.23	0.84	1.12	24.6	
13	ROB	10.46	13.4	0.17	0.43	1	0.1	0.43	0.4	13.47	
14											
15											
16											
17											
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LIVE SCOUR AT ABUTMENTS

Froehlich's Live-Bed Abutment Scour Equation — *LEFT* — *RIGHT* — ==========

$Ys/Ya = 2.27\ K_1\ K_2\ (L'/Ya)^{0.43}\ Fr^{0.61} + 1 =$ **1.49** **3.26** ……Eq. 7.1

Amended Local Scour Equation

$Ys/Ya = 2.27\ K_1\ K_2\ (L'/Ya)^{0.43}\ Fr^{0.61} + 0.05 =$ **0.54** **2.31** ……CT DOT DM Pg 9B-2

	LEFT	*RIGHT*		
Ys =	**0.31**	**2.73**	**m**	Scour depth <== using Amended equation
K_1 =	0.55	0.82		Coeffcient for abutment shape (see Table 7.1 and Figrue 7.6)
K_2 =	0.91	1.00		$(\theta/90)^{0.13}$, Coefficient for angle of embankment to flow
θ =	43	90		
				θ < 90 degrees if embankment points downstream
				θ > 90 degrees if embankment points upstream
				(see Figure 7.5 for definition of θ)
L' =	0.50	13.95	m	Length of active flow obstructed by the embankment (see Figure 7.4)
Ae =	0.29	34.92	m^2	Flow area of the approach cross section obstructed by the embankment
Fr =	0.27	0.24		Ve/(gYa)^0.5, Froude Number of approach flow upstream of the abutment
Ve =	0.65	0.82	m/s	Qe/Ae
Qe =	0.185	28.663	m^3/s	Flow obstructed by the abutment and approach embankment
Ya =	0.57	1.18	m	Ae/L, Average depth of flow on the floodplain
L =	0.5	29.633	m	Length of embankment projected normal to the flow

Table 7.1. Abutment Shape Coefficients.

Description	K_1
Vertical-wall abutment	1.00
Vertical-wall abutment with wing walls	0.82
Spill-through abutment	0.55

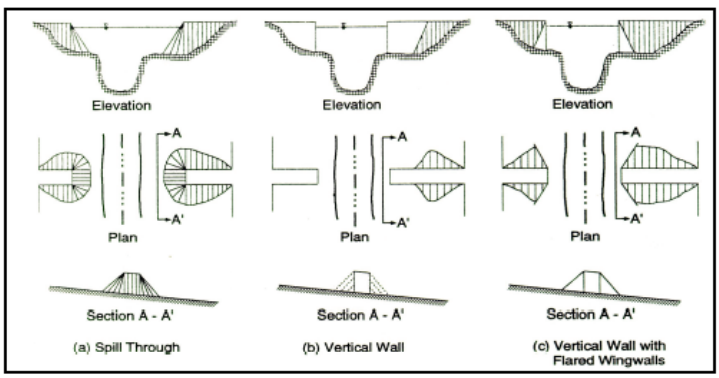


Figure 7.6. Abutment shape.

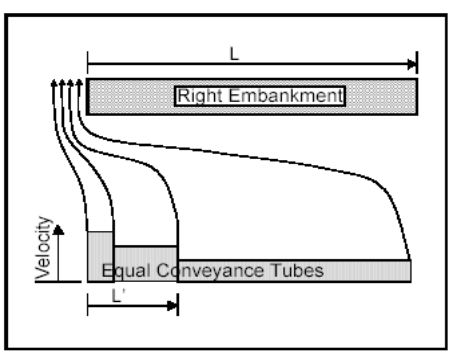


Figure 7.4. Determination of length of embankment blocking live flow for abutment scour estimation.

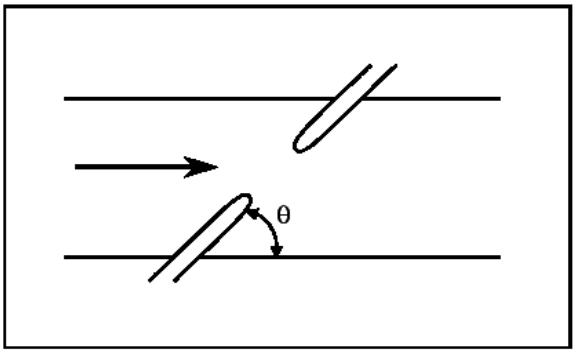


Figure 7.5. Orientation of embankment angle, θ, to the flow.

HIRE Live-Bed Abutment Scour Equation ==========

		LEFT	RIGHT	
Applicability check:	L/Y_1 =	0	12	*Use HIRE Eq. only if $L/Y_1 > 25$*
$Y_s/Y_1 = 4\ Fr^{0.33}\ K_1/0.55\ K_2$ =		**N/A**	**N/A**	……Eq. 7.1

	LEFT	RIGHT		
Y_s =	**N/A**	**N/A**	**m**	Scour depth (N/A if $L/Y_1 < 25$)
K1 =	0.55	0.82		Coeffcient for abutment shape (see Table 7.1 on RIGHT)
K2 =	0.91	1.00		$(\theta/90)^{0.13}$, Coefficient for angle of embankment to flow
Y1 =	2.43	2.43	m	Depth of flow at the abutment on the overbank or in the main channel,
Fr =	0.27	0.24		Ve/(gYa)^0.5, Froude Number of approach flow upstream of the abutment

Data Source

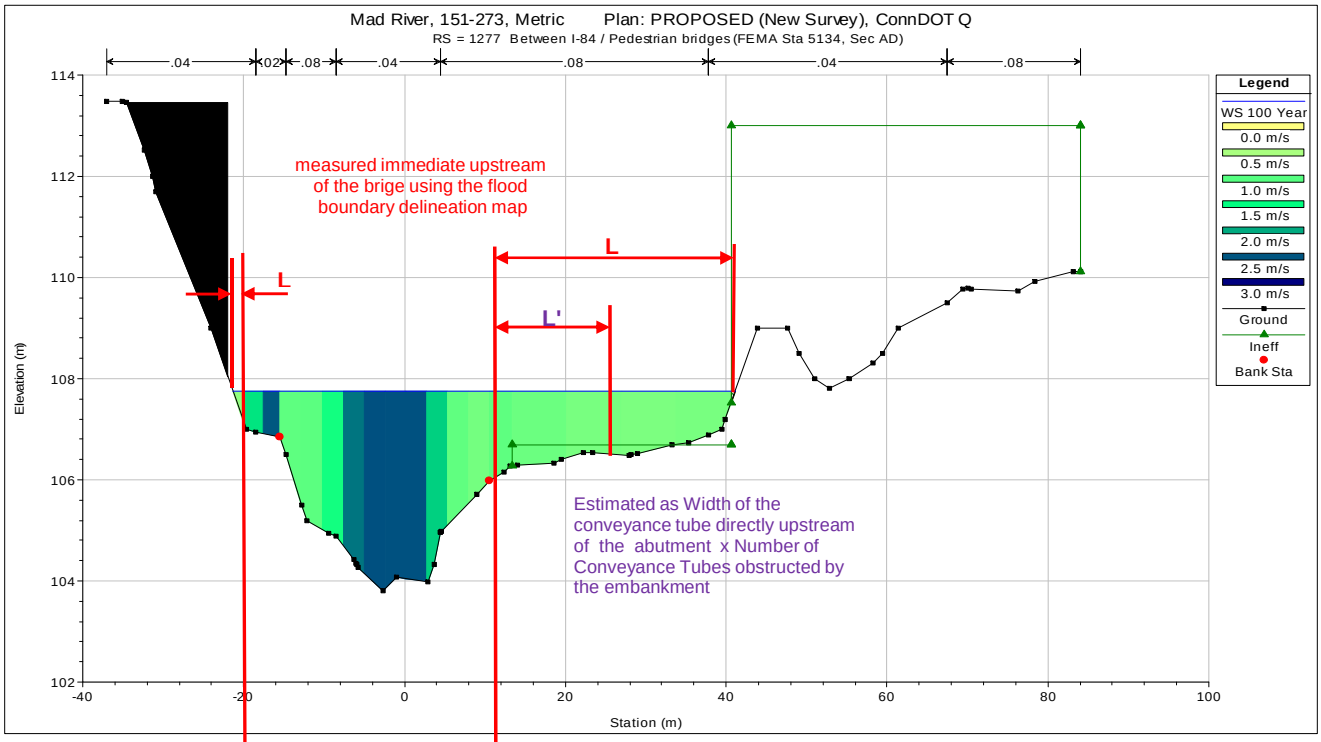
Eq. 7.1				From:	RS
LT				UC	
	L' =	0.5	m	D	1227
	Ae =	0.285	m2	D	1227
	Qe =	0.185	m3/s	D	1227
	L =	0.5	m	D	1227
RT				UC	
	L' =	13.95	m	D	1227
	Ae =	34.924	m2	D	1227
	Qe =	28.663	m3/s	D	1227
	L =	29.633	m	D	1227

Legends:

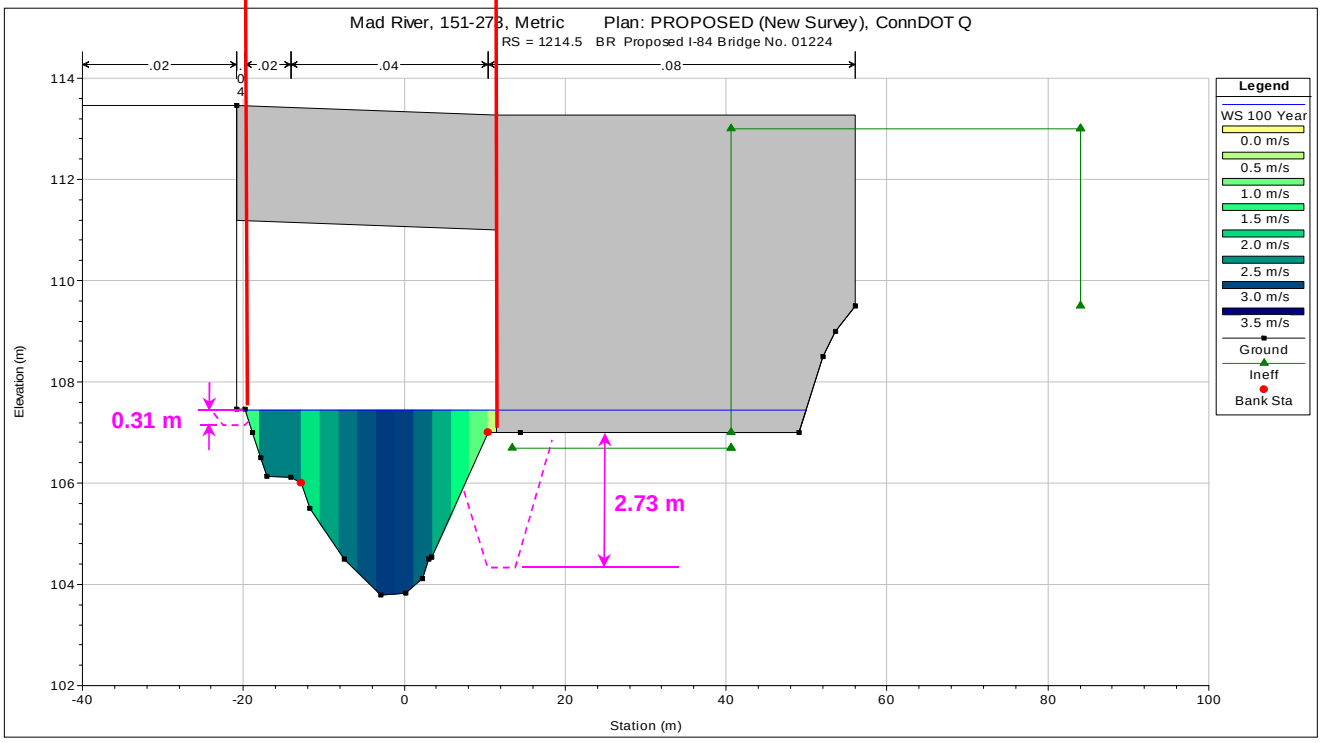
UC	from an upstream Cross Section output (approach section)
UF	from Bridge Upstream Face - Cross Section output (BR U); or Bridge Downstream Face (BR D) - this is seldom used
T	based on the flow data for the entire section
C	data from "Channel" column in the HEC-RAS Cross Section Output
D	from evaluting Flow Distribtion Output and resetting "Channel" and "Overbank" limits
M	manual data entry

Cross Sections Used for Local Abutment Scour Computations

APPROACH SECTION 1227



BRIDGE SECTION 1214.5 BR U



** This drawing is intended to provide as a basic, rough visualization of the scour depth. See Figure 5 for the more accurate depiction of combined total scour*

UPSTREAM APPROACH CHANNEL SECTION

River Station 1227 | Event: 100-YR

CROSS SECTION OUTPUT ***Use the same data as in the contraction scour computation?*** No | except channel stations

Plan: PR_DOT Mad River Reach 1 RS: 1277 Profile: 100 Year

		Element	Left OB	Channel	Right OB	Total
E.G. Elev (m)	107.89					
Vel Head (m)	0.15	Wt. n-Val.	0.024	0.06	0.077	
W.S. Elev (m)	107.74	Reach Len. (m)	18.58	18.58	18.58	
Crit W.S. (m)	106.52	Flow Area (m2)	4.12	75.68	36.23	
E.G. Slope (m/m)	0.003114	Area (m2)	4.12	75.68	36.28	116.08
Q Total (m3/s)	176.98	Flow (m3/s)	7.78	139.25	29.95	
Top Width (m)	62.43	Top Width (m)	5.89	26.06	30.47	
Vel Total (m/s)	1.53	Avg. Vel. (m/s)	1.89	1.84	0.83	
Max Chl Dpth (m)	3.93	Hydr. Depth (m)	0.7	2.9	1.21	1.86
Conv. Total (m3/s)	3171.7	Conv. (m3/s)	139.5	2495.6	536.7	
Length Wtd. (m)	18.58	Wetted Per. (m)	6.06	26.98	30.14	
Min Ch El (m)	103.81	Shear (N/m2)	20.79	85.65	36.7	
Alpha	1.26	Stream Power (N/m s)	4022.22	0	0	
Frctn Loss (m)	0.06	Cum Volume (1000 m3)	3.53	27.13	0.49	
C & E Loss (m)	0.06	Cum SA (1000 m2)	14.34	11.49	1.25	

	Flow dis.	*manual*
Left WS Sta.	-21.92	-21.34
Left Flood Sta.	-19.76	-21.34
Left Abutmnt Sta.	-20.84	
Right Abutmnt Sta.	11.45	
Right Flood Sta.	33.8	25.40
Right WS Sta.	47.83	41.08

L' (left)	0.5	L (left)	0.5
L' (Right)	13.95	L (Right)	29.633

FLOW DISTRIBUTION IN CROSS SECTION OUTPUT

	W1	Q1, Qe	Area	` Y1	V1
LEFT		0.185	0.285		
Main	32.287	148.132	80.891	2.51	1.83
Right		28.663	34.924		

Plan: PR_DOT Mad River Reach 1 RS: 1277 Profile: 100 Year

	Pos	Left Sta (m)	Right Sta (m)	Flow (m3/s)	Area (m2)	W.P. (m)	Percent Conv	Hydr Depth(m)	Velocity (m/s)	Shear (N/m2)	Power (N/m s)
1	LOB	-21.92	-19.76	0.37	0.57	1.74	0.21	0.36	0.65	9.97	
2	LOB	-19.76	-17.61	2.81	1.7	2.16	1.59	0.79	1.65	24.01	
3	LOB	-17.61	-15.45	4.6	1.86	2.16	2.6	0.86	2.48	26.29	
4	Chan	-15.45	-12.84	3.82	4.03	2.91	2.16	1.55	0.95	42.2	
5	Chan	-12.84	-10.24	6.43	6.68	2.69	3.63	2.56	0.96	75.66	
6	Chan	-10.24	-7.63	10.35	7.41	2.63	5.85	2.84	1.4	86.03	
7	Chan	-7.63	-5.03	20.02	8.67	2.66	11.31	3.33	2.31	99.37	
8	Chan	-5.03	-2.42	24.86	9.83	2.63	14.05	3.77	2.53	113.94	
9	Chan	-2.42	0.19	24.61	9.76	2.62	13.91	3.74	2.52	113.52	
10	Chan	0.19	2.79	24.52	9.71	2.61	13.85	3.72	2.53	113.69	
11	Chan	2.79	5.4	14.56	8.19	2.93	8.23	3.14	1.78	85.38	
12	Chan	5.4	8	5.86	6.27	2.64	3.31	2.41	0.94	72.46	
13	Chan	8	10.61	4.22	5.14	2.64	2.38	1.97	0.82	59.49	
14	ROB	10.61	13.4	4.29	4.52	2.81	2.42	1.62	0.95	49.2	
15	ROB	13.4	20.2	8.44	9.67	6.8	4.77	1.42	0.87	43.4	
16	ROB	20.2	27	6.64	8.38	6.8	3.75	1.23	0.79	37.6	
17	ROB	27	33.8	6.02	7.9	6.8	3.4	1.16	0.76	35.45	
18	ROB	33.8	40.6	4.56	5.76	6.92	2.58	0.85	0.79	25.39	
19	ROB	40.6	47.83	0	0.05	0.53	0	0.11	0	3.02	

	Left	Right
Computed L' = W x $\#_{tube}$ =	***2.16***	***13.95***
Width of Tube at Embankment	2.16	2.79
No. of Tubes on overbank	1	5

PROJECT NO. 151-273 **BRIDGE NO.** 01224 (Prop.) **UNIT:** Metric

Ref. HEC-18., May 2001 (4th ed.)

(October 2013 Note: These equation are still valid in HEC-18, 5th ed.)

SUMMARY

Contraction Scour		Type:	**LIVE-BED**	Depth:	**1.30** m	Event:	**500-YR**
Local	**East Abut. #2**	**LEFT**	Eq.: Froehlich	Depth:	**0.84** m	Event:	**500-YR**
Abutment	**West Abut. #1**	**RIGHT**	Eq.: Froehlich	Depth:	**3.42** m	Event:	**500-YR**

CONTRACTION SCOUR

$V_c = K_u\, y^{1/6}\, D^{1/3}$ ……Eq. 5.1

= 2.18 *m/s* Critacal velocity above which bed material of size D and smaller will be transported

Ku = 6.19 m (6.19 in SI units; 11.17 in English units)

y = 3.31 m Average depth of flow upstream of the bridge

D = 0.024 m Particle size for Vc *, m* (use D_{50})

V1 = 2.79 *m/s* The mean velocity of the flow in the main channel or overbank area upstream of the brige opening

Vc < V1 ***Thus, LIVE-BED CONTRACTION SCOUR***

Live-Bed Contraction Scour ==========

$Y_2/Y_1 = (Q_2/Q_1)^{6/7}\,(W_1/W_2)^{k_1}$ = 1.29 ……Eq. 5.2

$Y_s = Y_2 - Y_o$ m ……Eq. 5.3

= 1.30 m Average contraction scour depth

Y_1 = 3.31 m Average depth in the upstream main channel

Y_2 = 4.28 m Average depth in the contracted section

Y_o = 2.99 m Existing depth in the contracted section before scour

Q_1 = 212.29 m3/s Flow in the upstream channel transporting sediment

Q_2 = 269.01 m3/s Flow in the contracted channel

W_1 = 35.40 m Bottom width of the upstream main channel that is transporting bed material

W_2 = 32.26 m Bottom width of the main channel in the contracted section less pier width

k_1 = 0.59 Exponent determined below (V^*/ω = 0.45)

V^* = 0.2832 $=(T_o/\rho)^{1/2}$ or $(gY1\ S1)^{1/2}$, shear velocity in the upstream section , m/s

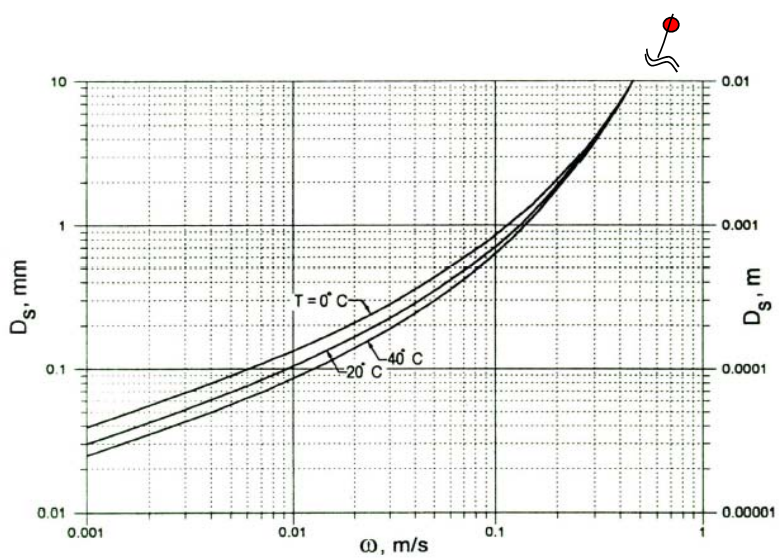
ω = 0.63 m/s Fall velocity of bed material based on the D_{50} (Figure 5.8)

g = 9.81 m/s^2 Acceleration of gravity

S1 = 0.002089 m/m Slope of energy gradeline of main channel

T_o = 80.22 Pa (N/m^2) Shear stess on the bed

ρ = 1000 kg/m^3 Density of water



V^*/ω	k1	*Mode of Bed Material Transport*
<0.50	0.59	Mostly contact bed material discharge
0.50 to 2.0	0.64	Some suspended bed material discharge
>2.0	0.69	Mostly suspended bed material discharge

Figure 5.8. Fall velocity of sand-sized particles with specific gravity of 2.65 in metric units.

Clear-Water Contraction Scour ==========

$$y_2 = \left[\frac{K_u Q^2}{D_m^{2/3} W^2} \right]^{3/7}$$ ……Eq. 5.4

y_s =	$y_2 - y_o$	m		……Eq. 5.5
=	N/A	m	Average contraction scour depth	**LIVE-BED controls. Ignore this procedure**
y_2 =	3.45	m	Average equilibrium depth in the contracted section after contraction scour	
y_o =	2.99	m	Average existing depth in the contracted section	
Q =	269.01	m3/s	Discharge through the bridge or on the set-back overbank area at the bridge associated with the width W	
W =	32.26	m	Bottom width of the contracted section less pier widths	
K_u =	0.0250		(0.025 in SI units; 0.0077 in English units)	
D_m =	0.0300	m	Diameter of the smallest nontransportable particle in the bed material (1.25 D50) in th contacted setion	
D_{50} =	0.0240	m	Median diameter of bed material	

Because D_{50} is not the largest particle in the bed material, the scoured section can be slightly armored. Therefore, the D_m is assumed to be 1.25 D_{50}. For stratified bed material the depth of scour can be determined by using the clear-water scour equation sequentially with successive D_m of the bed material layers.

Data Source

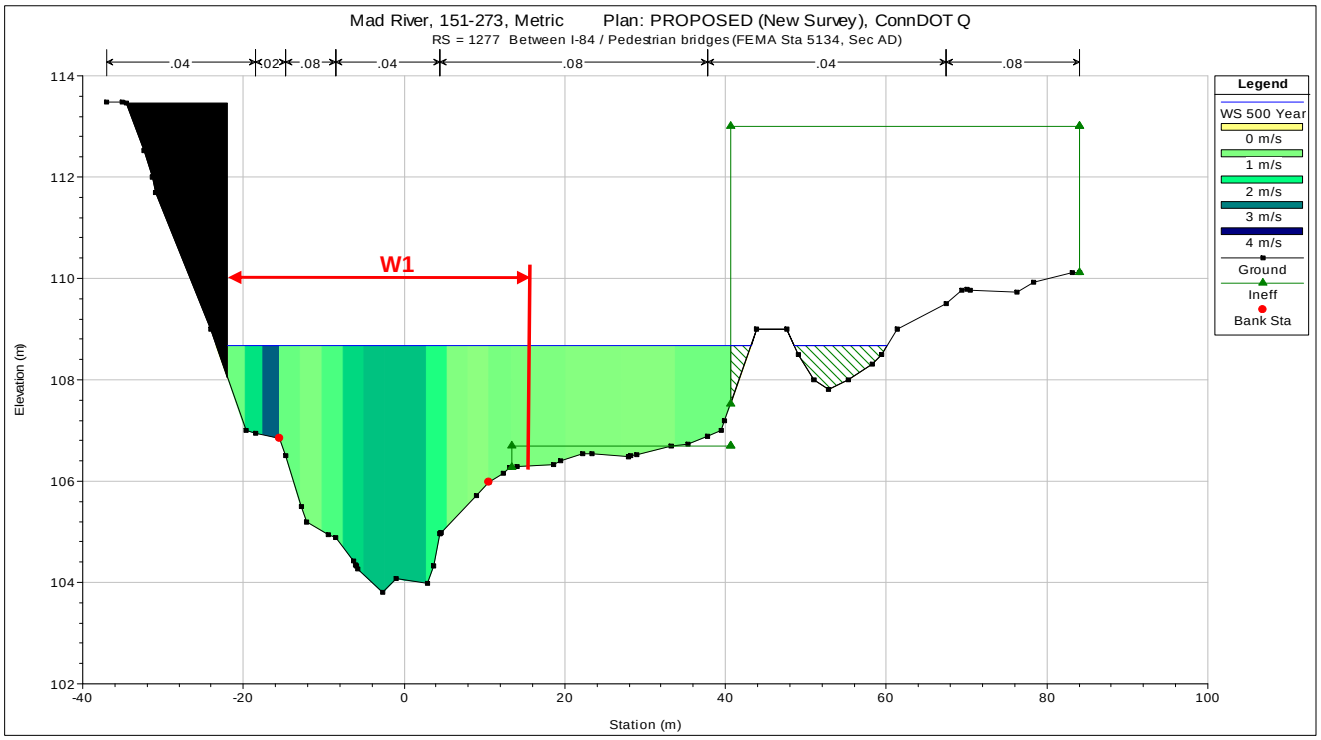
Eq. 5.1			From:	RS
y =	3.31	m	D	1277
V1 =	2.79	m	T	1214.5 BR U
Eq. 5.2 & 5.3				
Y1 =	3.31	m	D	1277
Yo =	2.99	m	T	1214.5 BR U
Q1 =	212.29	m3/s	D	1277
Q2 =	269.01	m3/s	T	1214.5 BR U
W1 =	35.4	m	D	1277
or	(n/a)	m (manual)		
W2 =	32.26	m	T	1214.5 BR U
or	(n/a)	m (manual)		
S1 =	0.002089	m/m	C	1277
To =	80.22	Pa (N/m^2)	C	1214.5 BR U
P2 =	0	m (pier width)		
Eq. 5.4 & 5.5				
Q =	269.01	m3/s	C	1214.5

Legends:

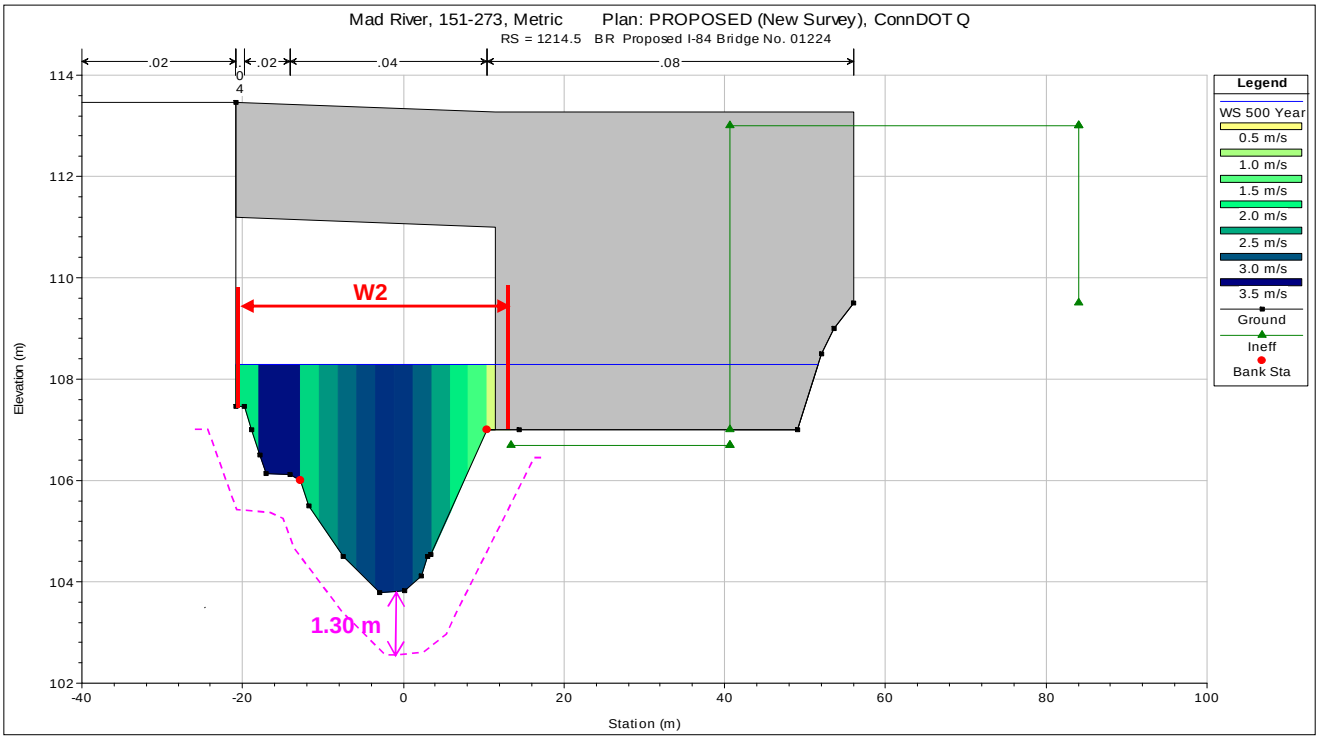
T	based on the flow data for the entire section
C	data from "Channel" column in the HEC-RAS Cross Section Output
D	from evaluting Flow Distribtion Output and resetting "Channel" and "Overbank" limits
M	manual data entry

Cross Sections used for Contraction Scour Computations

UPSTREAM SECTION 1277



CONTRACTED SECTION 1214.5 BR U



UPSTREAM CHANNEL SECTION

River Station 1277 Event: 500-YR

HEC-RAS CROSS SECTION OUTPUT

Plan: PR_DOT Mad River Reach 1 RS: 1277 Profile: 500 Year

E.G. Elev (m)	108.82	Element	Left OB	Channel	Right OB	Total
Vel Head (m)	0.15	Wt. n-Val.	0.025	0.06	0.076	
W.S. Elev (m)	108.67	Reach Len. (m)	18.58	18.58	18.58	
Crit W.S. (m)	107.2	Flow Area (m2)	10.11	99.87	64.08	
E.G. Slope (m/m)	0.002089	Area (m2)	10.11	99.87	71.66	181.64
Q Total (m3/s)	269.01	Flow (m3/s)	23.63	181.12	64.26	
Top Width (m)	76.68	Top Width (m)	6.55	26.06	44.07	
Vel Total (m/s)	1.55	Avg. Vel. (m/s)	2.34	1.81	1	
Max Chl Dpth (m)	4.86	Hydr. Depth (m)	1.54	3.83	2.14	2.37
Conv. Total (m3/s)	5885.4	Conv. (m3/s)	517	3962.7	1405.8	
Length Wtd. (m)	18.58	Wetted Per. (m)	7.41	26.98	30.14	
Min Ch El (m)	103.81	Shear (N/m2)	27.95	75.85	43.55	
Alpha	1.23	Stream Power (N/m s)	4022.22	0	0	
Frctn Loss (m)	0.04	Cum Volume (1000 m3)	21.88	34.58	3.66	
C & E Loss (m)	0.08	Cum SA (1000 m2)	37.95	11.52	7.52	

	Flow dis.	*manual*
Left WS Sta.	-22	-23.4
Left Convy Sta.		-23.4
Left Main Channel	-22	
Right Main Channel	13.4	
Right Convy Sta.	40.6	
Right WS Sta.		43.16
L' (left) 1.4	L (left)	1.4
L' (Right) 27.2	L (Right)	29.76

HEC-RAS FLOW DISTRIBUTION IN CROSS SECTION OUTPUT

	W1	Q1, Qe	Area	Y1	V1
LEFT					
Main	35.4	212.29	117.1	3.31	1.81
Right		56.73	64.53		

Plan: PR_DOT Mad River Reach 1 RS: 1277 Profile: 500 Year

	Pos	Left Sta (m)	Right Sta (m)	Flow (m3/s)	Area (m2)	W.P. (m)	Percent Conv	Hydr Depth(m)	Velocity (m/s)	Shear (N/m2)	Power (N/m s)
1	LOB	-24.07	-21.92	0.01	0.06	0.72	0	0.65	0.2	1.56	
2	LOB	-21.92	-19.76	2.85	2.49	2.37	1.06	1.16	1.14	21.6	
3	LOB	-19.76	-17.61	8.21	3.7	2.16	3.05	1.72	2.22	35.07	
4	LOB	-17.61	-15.45	12.56	3.86	2.16	4.67	1.79	3.26	36.65	
5	Chan	-15.45	-12.84	7.66	6.45	2.91	2.85	2.47	1.19	45.33	
6	Chan	-12.84	-10.24	9.12	9.1	2.69	3.39	3.49	1	69.16	
7	Chan	-10.24	-7.63	13.99	9.83	2.63	5.2	3.77	1.42	76.56	
8	Chan	-7.63	-5.03	25.56	11.09	2.66	9.5	4.26	2.31	85.28	
9	Chan	-5.03	-2.42	30.4	12.25	2.63	11.3	4.7	2.48	95.28	
10	Chan	-2.42	0.19	30.17	12.17	2.62	11.22	4.67	2.48	95.06	
11	Chan	0.19	2.79	30.1	12.13	2.61	11.19	4.65	2.48	95.31	
12	Chan	2.79	5.4	18.77	10.61	2.93	6.98	4.07	1.77	74.22	
13	Chan	5.4	8	8.56	8.69	2.64	3.18	3.33	0.99	67.38	
14	Chan	8	10.61	6.8	7.56	2.64	2.53	2.9	0.9	58.69	
15	ROB	10.61	13.4	7.53	7.11	2.81	2.8	2.55	1.06	51.92	
16	ROB	13.4	20.2	16.09	15.99	6.8	5.98	2.35	1.01	48.13	
17	ROB	20.2	27	13.98	14.69	6.8	5.2	2.16	0.95	44.25	
18	ROB	27	33.8	13.22	14.21	6.8	4.92	2.09	0.93	42.8	
19	ROB	33.8	40.6	13.44	12.07	6.92	5	1.78	1.11	35.73	
20	ROB	40.6	47.83	0	1.46	2.8	0	0.57	0	10.71	
21	ROB	47.83	55.07	0	4.04	6.64	0	0.62	0	12.48	
22	ROB	55.07	62.3	0	2.07	5.05	0	0.42	0	8.42	

CONTRACTED CHANNEL SECTION

River Station 1214.5 BR U

CROSS SECTION OUTPUT

Plan: PR_DOT Mad River Reach 1 RS: 1214.5 BR U Profile: 500 Year

E.G. Elev (m)	108.7	Element	Left OB	Channel	Right OB	Total
Vel Head (m)	0.41	Wt. n-Val.	0.023	0.04	0.08	
W.S. Elev (m)	108.3	Reach Len. (m)	89.02	89.02	89.02	
Crit W.S. (m)	107.19	Flow Area (m2)	14.47	80.53	1.3	
E.G. Slope (m/m)	0.002436	Area (m2)	14.47	80.53	1.3	96.3
Q Total (m3/s)	269.01	Flow (m3/s)	45.26	222.8	0.95	
Top Width (m)	32.26	Top Width (m)	8.08	23.18	1	
Vel Total (m/s)	2.79	Avg. Vel. (m/s)	3.13	2.77	0.73	
Max Chl Dpth (m)	4.5	Hydr. Depth (m)	1.79	3.47	1.3	2.99
Conv. Total (m3/s)	5450.2	Conv. (m3/s)	916.9	4514.1	19.2	
Length Wtd. (m)	89.02	Wetted Per. (m)	9.22	23.98	1	
Min Ch El (m)	103.79	Shear (N/m2)	37.47	80.22	30.95	
Alpha	1.02	Stream Power (N/m s)	2681.16	0	0	
Frctn Loss (m)	0.4	Cum Volume (1000 m3)	21.66	32.91	2.99	
C & E Loss (m)	0.22	Cum SA (1000 m2)	37.81	11.07	7.1	

	Flow dis.	*manual*
Left WS Sta.		-20.8
Left Flood Sta.		-20.8
Left Main Channel	-19.81	
Right Main Channel	10.46	
Right Flood Sta.		11.46
Right WS Sta.		11.46
L' (left) 0.9944	L (left)	0.9944
L' (Right) 1	L (Right)	1

FLOW DISTRIBUTION IN CROSS SECTION OUTPUT

	W1	Q1, Qe	Area	Y1	V1
LEFT		4.44	2.0672		
Main	30.2656	263.63	92.9028	3.07	2.84
Right		0.95	1.3		

Plan: PR_DOT Mad River Reach 1 RS: 1214.5 BR U Profile: 500 Year

Pos	Left Sta (m)	Right Sta (m)	Flow (m3/s)	Area (m2)	W.P. (m)	Percent Conv	Hydr Depth(m)	Velocity (m/s)	Shear (N/m2)	Power (N/m s)
1 LOB	-23.14	-17.93	6.93	3.23	3.91	2.58	1.13	2.14	19.75	
2 LOB	-17.93	-12.72	38.32	11.23	5.31	14.25	2.16	3.41	50.52	
3 Chan	-12.72	-10.4	14.39	6.42	2.47	5.35	2.77	2.24	62.14	
4 Chan	-10.4	-8.08	20.41	7.8	2.38	7.59	3.37	2.62	78.35	
5 Chan	-8.08	-5.77	25.83	8.95	2.36	9.6	3.86	2.89	90.78	
6 Chan	-5.77	-3.45	30.2	9.82	2.35	11.23	4.23	3.08	99.95	
7 Chan	-3.45	-1.13	33.42	10.39	2.32	12.42	4.48	3.22	106.8	
8 Chan	-1.13	1.19	32.79	10.28	2.33	12.19	4.44	3.19	105.5	
9 Chan	1.19	3.51	27.64	9.41	2.41	10.27	4.06	2.94	93.18	
10 Chan	3.51	5.82	19.5	7.69	2.45	7.25	3.32	2.54	74.81	
11 Chan	5.82	8.14	12.24	5.81	2.45	4.55	2.51	2.11	56.58	
12 Chan	8.14	10.46	6.4	3.94	2.45	2.38	1.7	1.62	38.34	
13 ROB	10.46	13.4	0.95	1.3	1	0.35	1.3	0.73	30.95	
14										
15										
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LIVE SCOUR AT ABUTMENTS

Froehlich's Live-Bed Abutment Scour Equation — *LEFT* — *RIGHT* — ==========

$Ys/Ya = 2.27\ K_1\ K_2\ (L'/Ya)^{0.43}\ Fr^{0.61} + 1 =$ — **2.41** — **2.51** — .....Eq. 7.1

Amended Local Scour Equation

$Ys/Ya = 2.27\ K_1\ K_2\ (L'/Ya)^{0.43}\ Fr^{0.61} + 0.05 =$ — **1.46** — **1.56** — .....CT DOT DM Pg 9B-2

	LEFT	*RIGHT*		
Ys =	**0.84**	**3.42**	**m**	Scour depth <== using Amended equation
K_1 =	0.82	0.82		Coeffcient for abutment shape (see Table 7.1 and Figrue 7.6)
K_2 =	0.91	1.00		$(\theta/90)^{0.13}$, Coefficient for angle of embankment to flow
θ =	43	90		
				θ < 90 degrees if embankment points downstream
				θ > 90 degrees if embankment points upstream
				(see Figure 7.5 for definition of θ)
L' =	1.12	13.95	m	Length of active flow obstructed by the embankment (see Figure 7.4)
Ae =	1.35	69.51	m^2	Flow area of the approach cross section obstructed by the embankment
Fr =	0.46	0.19		Ve/(gYa)^0.5, Froude Number of approach flow upstream of the abutment
Ve =	1.10	0.89	m/s	Qe/Ae
Qe =	1.492	62.001	m^3/s	Flow obstructed by the abutment and approach embankment
Ya =	0.58	2.19	m	Ae/L, Average depth of flow on the floodplain
L =	2.3432	31.713	m	Length of embankment projected normal to the flow

Table 7.1. Abutment Shape Coefficients.

Description	K_1
Vertical-wall abutment	1.00
Vertical-wall abutment with wing walls	0.82
Spill-through abutment	0.55

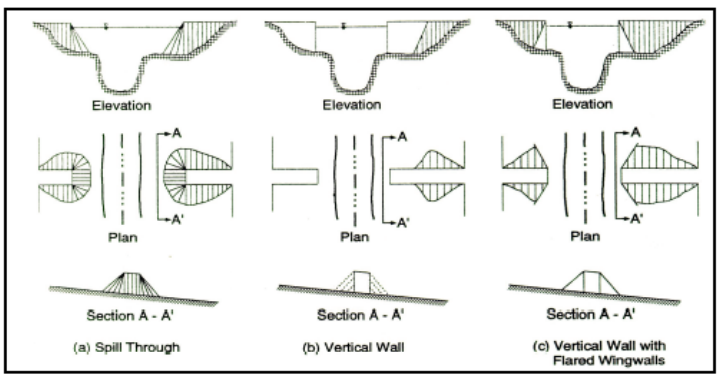


Figure 7.6. Abutment shape.

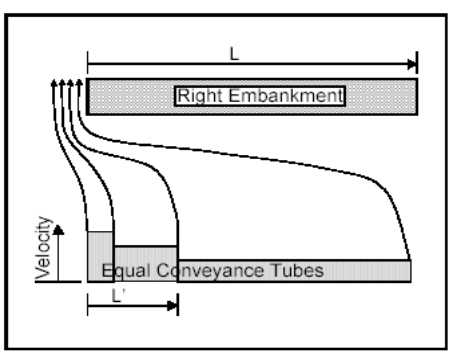


Figure 7.4. Determination of length of embankment blocking live flow for abutment scour estimation.

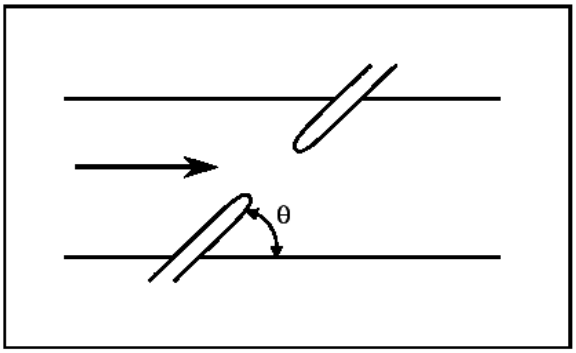


Figure 7.5. Orientation of embankment angle, θ, to the flow.

HIRE Live-Bed Abutment Scour Equation ==========

		LEFT	RIGHT	
Applicability check:	L/Y_1 =	1	10	*Use HIRE Eq. only if $L/Y_1 > 25$*
$Y_s/Y_1 = 4\ Fr^{0.33}\ K_1/0.55\ K_2$ =		**N/A**	**N/A**	……Eq. 7.1

	LEFT	RIGHT		
Y_s =	**N/A**	**N/A**	**m**	Scour depth (N/A if $L/Y_1 < 25$)
K1 =	0.82	0.82		Coeffcient for abutment shape (see Table 7.1 on RIGHT)
K2 =	0.91	1.00		$(\theta/90)^{0.13}$, Coefficient for angle of embankment to flow
Y1 =	3.31	3.31	m	Depth of flow at the abutment on the overbank or in the main channel,
Fr =	0.46	0.19		Ve/(gYa)^0.5, Froude Number of approach flow upstream of the abutment

Data Source

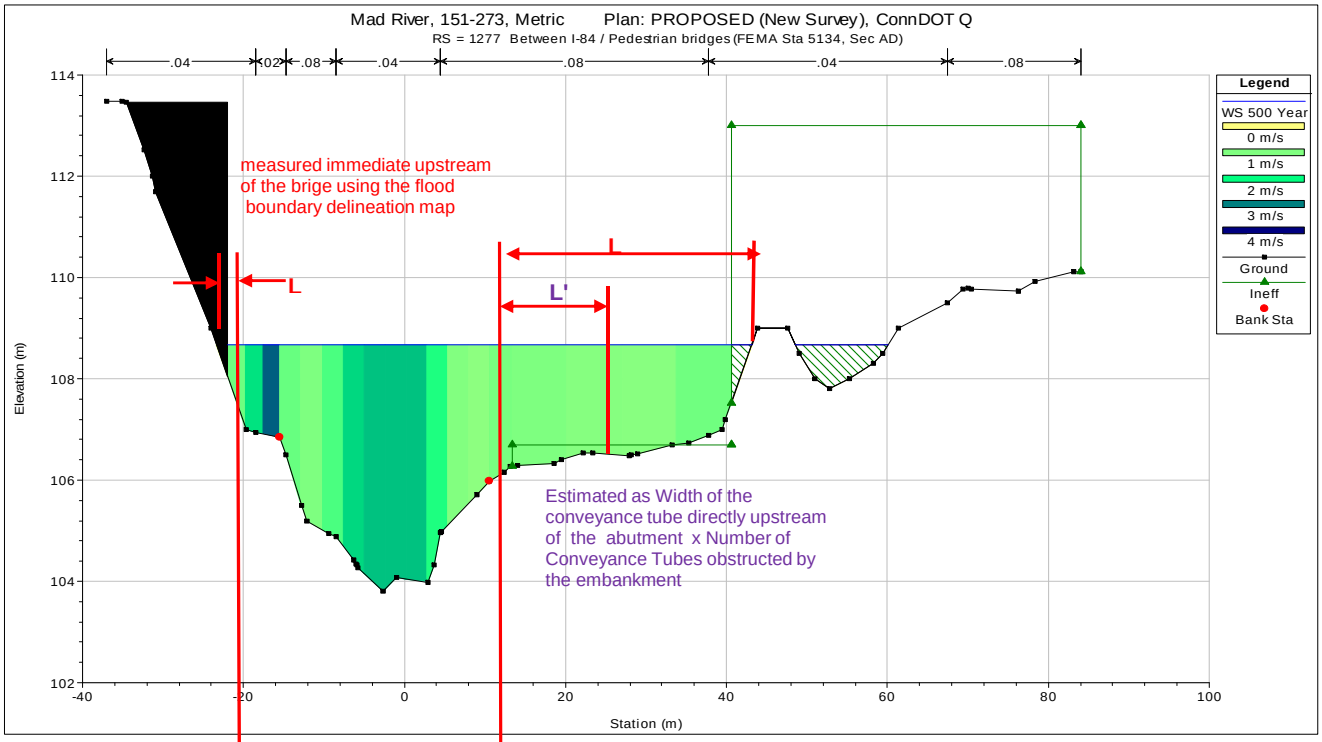
Eq. 7.1				From:	RS
LT				UC	
	L' =	1.1232	m	D	1227
	Ae =	1.3548	m2	D	1227
	Qe =	1.492	m3/s	D	1227
	L =	2.3432	m	D	1227
RT				UC	
	L' =	13.95	m	D	1227
	Ae =	69.507	m2	D	1227
	Qe =	62.001	m3/s	D	1227
	L =	31.713	m	D	1227

Legends:

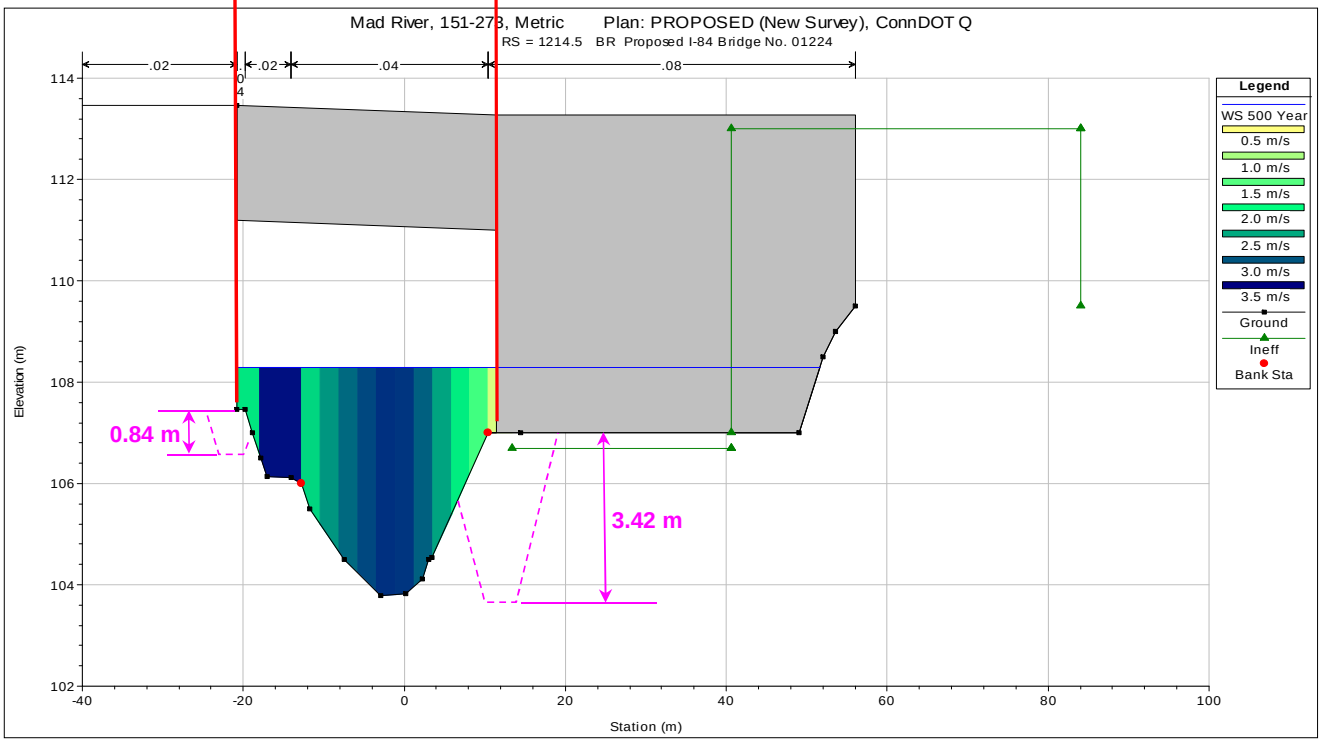
UC	from an upstream Cross Section output (approach section)
UF	from Bridge Upstream Face - Cross Section output (BR U); or Bridge Downstream Face (BR D) - this is seldom used
T	based on the flow data for the entire section
C	data from "Channel" column in the HEC-RAS Cross Section Output
D	from evaluting Flow Distribtion Output and resetting "Channel" and "Overbank" limits
M	manual data entry

Cross Sections Used for Local Abutment Scour Computations

APPROACH SECTION 1227



BRIDGE SECTION 1214.5 BR U



UPSTREAM APPROACH CHANNEL SECTION

River Station 1227 | Event: 500-YR

CROSS SECTION OUTPUT ***Use the same data as in the contraction scour computation?*** No | except channel stations

Plan: PR_DOT Mad River Reach 1 RS: 1277 Profile: 500 Year

E.G. Elev (m)	108.82	Element	Left OB	Channel	Right OB		Total
Vel Head (m)	0.15	Wt. n-Val.	0.025	0.06	0.076		
W.S. Elev (m)	108.67	Reach Len. (m)	18.58	18.58	18.58		
Crit W.S. (m)	107.2	Flow Area (m2)	10.11	99.87	64.08		
E.G. Slope (m/m)	0.002089	Area (m2)	10.11	99.87	71.66		181.64
Q Total (m3/s)	269.01	Flow (m3/s)	23.63	181.12	64.26		
Top Width (m)	76.68	Top Width (m)	6.55	26.06	44.07		
Vel Total (m/s)	1.55	Avg. Vel. (m/s)	2.34	1.81	1		
Max Chl Dpth (m)	4.86	Hydr. Depth (m)	1.54	3.83	2.14		2.37
Conv. Total (m3/s)	5885.4	Conv. (m3/s)	517	3962.7	1405.8		
Length Wtd. (m)	18.58	Wetted Per. (m)	7.41	26.98	30.14		
Min Ch El (m)	103.81	Shear (N/m2)	27.95	75.85	43.55		
Alpha	1.23	Stream Power (N/m s)	4022.22	0	0		
Frctn Loss (m)	0.04	Cum Volume (1000 m3)	21.88	34.58	3.66		
C & E Loss (m)	0.08	Cum SA (1000 m2)	37.95	11.52	7.52		

	Flow dis.	*manual*
Left WS Sta.	-24.07	-23.14
Left Flood Sta.	-21.92	
Left Abutmnt Sta.	-20.80	
Right Abutmnt Sta.	11.45	
Right Flood Sta.	33.8	25.40
Right WS Sta.	40.6	43.16
8.233865 L' (left)	1.1232	L (left) 2.3432
L' (Right)	13.9500	L (Right) 31.713

FLOW DISTRIBUTION IN CROSS SECTION OUTPUT

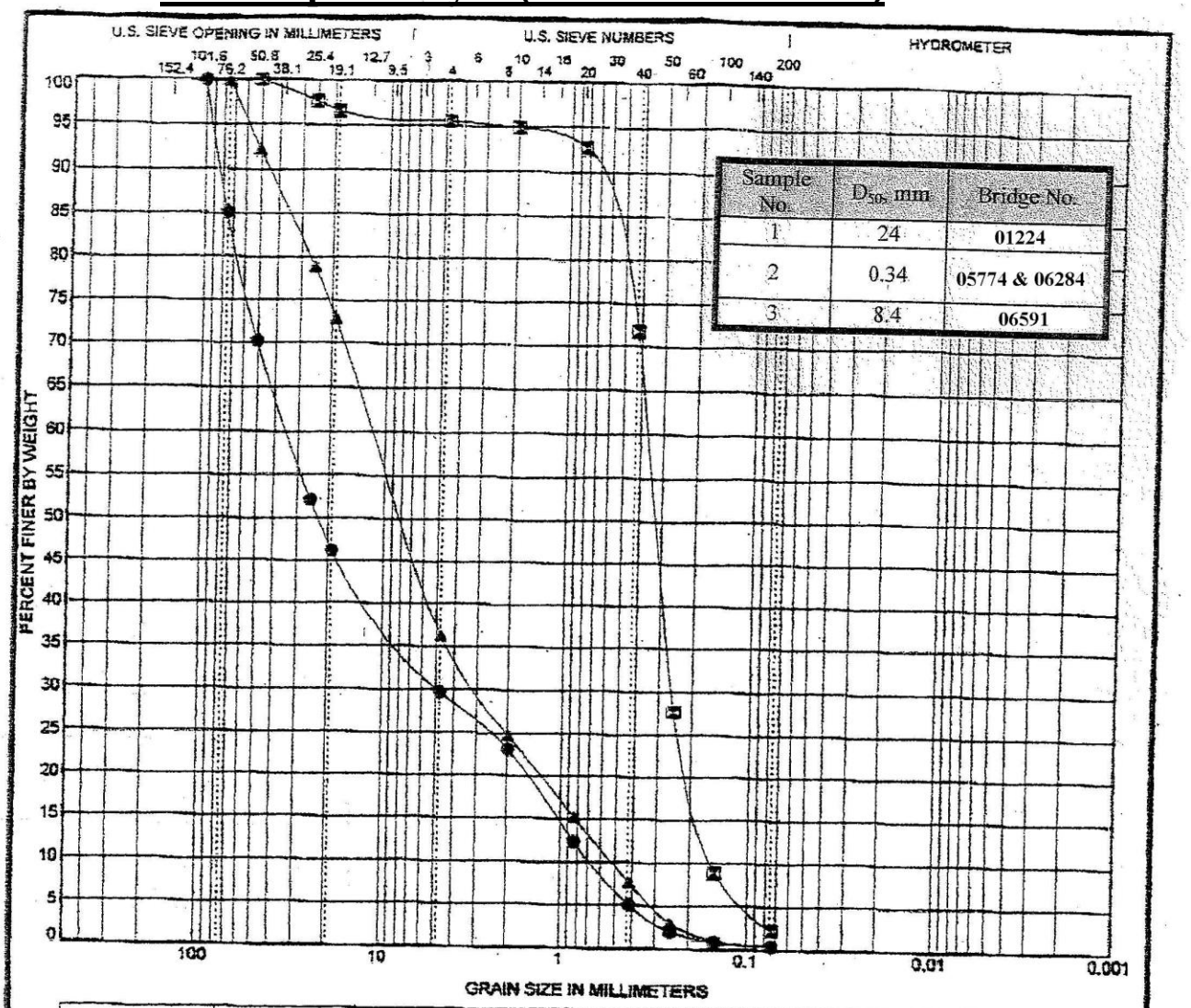
	W1	Q1, Qe	Area	` Y1	V1
LEFT		1.492	1.3548		
Main	32.2438	205.527	110.7682	3.44	1.86
Right		62.001	69.507		

Plan: PR_DOT Mad River Reach 1 RS: 1277 Profile: 500 Year

	Pos	Left Sta (m)	Right Sta (m)	Flow (m3/s)	Area (m2)	W.P. (m)	Percent Conv	Hydr Depth(m)	Velocity (m/s)	Shear (N/m2)	Power (N/m s)
1	LOB	-24.07	-21.92	0.01	0.06	0.72	0	0.65	0.2	1.56	0.31
2	LOB	-21.92	-19.76	2.85	2.49	2.37	1.06	1.16	1.14	21.6	24.72
3	LOB	-19.76	-17.61	8.21	3.7	2.16	3.05	1.72	2.22	35.07	77.77
4	LOB	-17.61	-15.45	12.56	3.86	2.16	4.67	1.79	3.26	36.65	119.31
5	Chan	-15.45	-12.84	7.66	6.45	2.91	2.85	2.47	1.19	45.33	53.88
6	Chan	-12.84	-10.24	9.12	9.1	2.69	3.39	3.49	1	69.16	69.32
7	Chan	-10.24	-7.63	13.99	9.83	2.63	5.2	3.77	1.42	76.56	108.91
8	Chan	-7.63	-5.03	25.56	11.09	2.66	9.5	4.26	2.31	85.28	196.58
9	Chan	-5.03	-2.42	30.4	12.25	2.63	11.3	4.7	2.48	95.28	236.46
10	Chan	-2.42	0.19	30.17	12.17	2.62	11.22	4.67	2.48	95.06	235.56
11	Chan	0.19	2.79	30.1	12.13	2.61	11.19	4.65	2.48	95.31	236.58
12	Chan	2.79	5.4	18.77	10.61	2.93	6.98	4.07	1.77	74.22	131.38
13	Chan	5.4	8	8.56	8.69	2.64	3.18	3.33	0.99	67.38	66.38
14	Chan	8	10.61	6.8	7.56	2.64	2.53	2.9	0.9	58.69	52.73
15	ROB	10.61	13.4	7.53	7.11	2.81	2.8	2.55	1.06	51.92	54.95
16	ROB	13.4	20.2	16.09	15.99	6.8	5.98	2.35	1.01	48.13	48.43
17	ROB	20.2	27	13.98	14.69	6.8	5.2	2.16	0.95	44.25	42.09
18	ROB	27	33.8	13.22	14.21	6.8	4.92	2.09	0.93	42.8	39.82
19	ROB	33.8	40.6	13.44	12.07	6.92	5	1.78	1.11	35.73	39.78
20	ROB	40.6	47.83	0	1.46	2.8	0	0.57	0	10.71	0
21	ROB	47.83	55.07	0	4.04	6.64	0	0.62	0	12.48	0
22	ROB	55.07	62.3	0	2.07	5.05	0	0.42	0	8.42	0

	Left	Right
Computed L' = W x $\#_{tube}$ =	***4.32***	***13.95***
Width of Tube at Embankment	2.16	2.79
No. of Tubes on overbank	2	5

Soil Sample Analysis (Streambed Material)



Sample No.	D_{50}, mm	Bridge No.
1	24	01224
2	0.34	05774 & 06284
3	8.4	06591

	COBBLES	% GRAVEL			% SAND		% FINES	
		COARSE	MEDIUM	FINE	COARSE	FINE	% SILT	% CLAY
●	14.9	32.4	14.3	14.8	18.0	4.7	0.4	
■	0.0	2.4	1.5	1.1	23.2	69.6	2.2	
▲	0.0	20.8	24.5	29.8	17.0	7.2	0.5	

	Expl. No.	Sample No.	Depth (m)	LL	PL	PI	Water Content (%)	Cc	Cu
●	TP	1					6.2	1.04	51.02
■	TP	2					21.2	1.17	2.38
▲	TP	3					5.6	1.46	22.48

Sample Description

● Brown coarse to fine GRAVEL, little cobbles, little coarse sand, trace fine sand

■ Light brown coarse to fine SAND, trace coarse to fine gravel, trace silt

▲ Orange brown coarse to fine GRAVEL, little coarse sand, trace fine sand

Remarks:

HALEY & ALDRICH
Glastonbury, Connecticut

I-84 Reconstruction
Waterbury, Connecticut
State Project No.:

GRAIN SIZE DISTRIBUTION

Date: 12/17/2000

File No.: 91313-100

CONN DOT SIEVE 91313B.GPJ US LAB.GDT 12/20/00

Appendix C: Riprap Revetment Calculations

Based on the 100- and 500-Year DOT Design Discharges

- 100-YR
  - Upstream of Bridge (RS 1277)
  - Inside the Bridge – Upstream End (RS 1214.5 BR U)
  - Inside the Bridge – Downstream End (RS 1214.5 BR D)
  - Downstream of Bridge (RS 1162)
  - Downstream of Bridge (RS 1153)

- 500-YR
  - Upstream of Bridge (RS 1277)
  - Inside the Bridge – Upstream End (RS 1214.5 BR U)
  - Inside the Bridge – Downstream End (RS 1214.5 BR D)
  - Downstream of Bridge (RS 1162)
  - Downstream of Bridge (RS 1153)

- ACOE, EM 1110-2-1601 Method

- Filter Layer Check
  - Standard Riprap to Granular Fill
  - Granular Fill to native material
  - Soil Sample Analysis (channel bank, using S4-3)

Connecticut Department of Transportation

Project No.	**151-273 (Br.#01224)**	**Prepared by**	WS	**Date**	Oct. 2013
Route No.	**I-84**	**Checked by**		**Date**	
Town	**Waterbury**	**Stream**	Mad River		
Discharge	**100 Year**	**Unit**	Metric		

Riprap Revetment Design Based on HEC-11

$$D_{50} = 0.00594\ Va^3/(d_{avg} 0.5\ K_1^{1.5})\ C_{sf}$$

Average velocity (Va) and Average flow depth(d ave) in main channel

Cross Section No.	1277	Va (m/s)=	1.84
Flow Area (sq.m)=	116.03	Top Width (m)=	62.43
d avg (m) =	1.86		
Side Slope=	2 : 1	Bank angle (degrees) θ =	26.6

Riprap Class	Φ	K_1	D_{50}	Acceptable Range	Check
Modified	41.2	0.7342	**0.04**	d50 < 0.13m	G
Intermediate	41.6	0.7391	**0.04**	0.13m<d50<0.20m	G
Standard	41.8	0.7415	**0.04**	0.20m<d50<0.38m	G
Other	42	0.7438	**0.04**	d50>0.38m	

Assumed Specific Gravity of Rock Riprap = 2.65
Angle of Repose (degrees)= Φ
Bank Stability Factor =K1
Median riprap particle size (m) for Stabilty Factor of 1.2 = D50
use larger Stability Factor if applying at channel bends

Stability Factors (SF) and Correction Factor (C_{sf})

SF	C_{sf}	D_{50} (Φ = 41.2)	D_{50} (Φ = 41.6)	D_{50} (Φ = 41.8)	D_{50}| Φ = 42
1.0	0.76	**0.03**	**0.03**	**0.03**	**0.03**
1.1	0.88	**0.04**	**0.04**	**0.04**	**0.04**
1.2	1.00	**0.04**	**0.04**	**0.04**	**0.04**
1.3	1.13	**0.05**	**0.05**	**0.05**	**0.05**
1.4	1.26	**0.05**	**0.05**	**0.05**	**0.05**
1.5	1.40	**0.06**	**0.06**	**0.06**	**0.06**
1.6	1.54	**0.07**	**0.07**	**0.07**	**0.07**
1.7	1.69	**0.07**	**0.07**	**0.07**	**0.07**
1.8	1.84	**0.08**	**0.08**	**0.08**	**0.08**
1.9	1.99	**0.09**	**0.09**	**0.08**	**0.08**
2.0	2.15	**0.09**	**0.09**	**0.09**	**0.09**

Recommendation: Standard Riprap is adequate

Connecticut Department of Transportation

Project No.	**151-273 (Br.#01224)**	**Prepared by**	WS	**Date**	Oct. 2013
Route No.	**I-84**	**Checked by**		**Date**	
Town	**Waterbury**	**Stream**	Mad River		
Discharge	**100 Year**	**Unit**	Metric		

Riprap Revetment Design Based on HEC-11

$$D_{50} = 0.00594\ Va^3/(d_{avg} 0.5\ K_1^{1.5})\ C_{sf}$$

Average velocity (Va) and Average flow depth(d ave) in main channel

Cross Section No.	1214.5 BR U	Va (m/s)=	2.89
Flow Area (sq.m)=	61.19	Top Width (m)=	25.10
d avg (m) =	2.44		

Side Slope= 2 : 1

Bank angle (degrees)
θ = 26.6

Riprap Class	Φ	K_1	D_{50}	Acceptable Range	Check
Modified	41.2	0.7342	**0.15**	d50 < 0.13m	NG
Intermediate	41.6	0.7391	**0.14**	0.13m<d50<0.20m	G
Standard	41.8	0.7415	**0.14**	0.20m<d50<0.38m	G
Other	42	0.7438	**0.14**	d50>0.38m	

Assumed Specific Gravity of Rock Riprap = 2.65
Angle of Repose (degrees)= Φ
Bank Stability Factor =K1
Median riprap particle size (m) for Stabilty Factor of 1.2 = D50
use larger Stability Factor if applying at channel bends

Stability Factors (SF) and Correction Factor (C_{sf})

SF	C_{sf}	D_{50} (Φ = 41.2)	D_{50} (Φ = 41.6)	D_{50} (Φ = 41.8)	D_{50}| Φ = 42
1.0	0.76	**0.11**	**0.11**	**0.11**	**0.11**
1.1	0.88	**0.13**	**0.13**	**0.13**	**0.13**
1.2	1.00	**0.15**	**0.14**	**0.14**	**0.14**
1.3	1.13	**0.16**	**0.16**	**0.16**	**0.16**
1.4	1.26	**0.18**	**0.18**	**0.18**	**0.18**
1.5	1.40	**0.20**	**0.20**	**0.20**	**0.20**
1.6	1.54	**0.22**	**0.22**	**0.22**	**0.22**
1.7	1.69	**0.25**	**0.24**	**0.24**	**0.24**
1.8	1.84	**0.27**	**0.27**	**0.26**	**0.26**
1.9	1.99	**0.29**	**0.29**	**0.29**	**0.29**
2.0	2.15	**0.31**	**0.31**	**0.31**	**0.31**

Recommendation: Standard Riprap is adequate

Connecticut Department of Transportation

Project No.	**151-273 (Br.#01224)**	**Prepared by**	WS	**Date**	Oct. 2013
Route No.	**I-84**	**Checked by**		**Date**	
Town	**Waterbury**	**Stream**	Mad River		
Discharge	**100 Year**	**Unit**	Metric		

Riprap Revetment Design Based on HEC-11

$$D_{50} = 0.00594\ Va^3/(d_{avg} 0.5\ K_1^{1.5})\ C_{sf}$$

Average velocity (Va) and Average flow depth(d ave) in main channel

Cross Section No.	1214.5 BR D	Va (m/s)=	2.85
Flow Area (sq.m)=	62.13	Top Width (m)=	25.56
d avg (m) =	2.43		
Side Slope=	2 : 1	Bank angle (degrees) θ =	26.6

Riprap Class	Φ	K_1	D_{50}	Acceptable Range	Check
Modified	41.2	0.7342	**0.14**	d50 < 0.13m	NG
Intermediate	41.6	0.7391	**0.14**	0.13m<d50<0.20m	G
Standard	41.8	0.7415	**0.14**	0.20m<d50<0.38m	G
Heavy Riprap	42	0.7438	**0.14**	d50>0.38m	

Assumed Specific Gravity of Rock Riprap = 2.65
Angle of Repose (degrees)= Φ
Bank Stability Factor =K1
Median riprap particle size (m) for Stabilty Factor of 1.2 = D50
use larger Stability Factor if applying at channel bends

Stability Factors (SF) and Correction Factor (C_{sf})

SF	C_{sf}	D_{50} (Φ = 41.2)	D_{50} (Φ = 41.6)	D_{50} (Φ = 41.8)	D_{50} | Φ = 42
1.0	0.76	**0.11**	**0.11**	**0.11**	**0.10**
1.1	0.88	**0.12**	**0.12**	**0.12**	**0.12**
1.2	1.00	**0.14**	**0.14**	**0.14**	**0.14**
1.3	1.13	**0.16**	**0.16**	**0.16**	**0.16**
1.4	1.26	**0.18**	**0.17**	**0.17**	**0.17**
1.5	1.40	**0.20**	**0.19**	**0.19**	**0.19**
1.6	1.54	**0.22**	**0.21**	**0.21**	**0.21**
1.7	1.69	**0.24**	**0.23**	**0.23**	**0.23**
1.8	1.84	**0.26**	**0.25**	**0.25**	**0.25**
1.9	1.99	**0.28**	**0.28**	**0.28**	**0.27**
2.0	2.15	**0.30**	**0.30**	**0.30**	**0.30**

Recommendation: Standard Riprap is adequate

Connecticut Department of Transportation

Project No.	**151-273 (Br.#01224)**	**Prepared by**	WS	**Date**	Oct. 2013
Route No.	**I-84**	**Checked by**		**Date**	
Town	**Waterbury**	**Stream**	Mad River		
Discharge	**100 Year**	**Unit**	Metric		

Riprap Revetment Design Based on HEC-11

$$D_{50} = 0.00594\ Va^3/(d_{avg} 0.5\ K_1^{1.5})\ C_{sf}$$

Average velocity (Va) and Average flow depth(d ave) in main channel

Cross Section No.	1162	Va (m/s)=	3.36
Flow Area (sq.m)=	52.47	Top Width (m)=	20.63
d avg (m) =	2.54		
Side Slope=	2 : 1	Bank angle (degrees) θ =	26.6

Riprap Class	Φ	K_1	D_{50}	Acceptable Range	Check
Modified	41.2	0.7342	**0.22**	d50 < 0.13m	NG
Intermediate	41.6	0.7391	**0.22**	0.13m<d50<0.20m	NG
Standard	41.8	0.7415	**0.22**	0.20m<d50<0.38m	G
Other	42	0.7438	**0.22**	d50>0.38m	

Assumed Specific Gravity of Rock Riprap = 2.65
Angle of Repose (degrees)= Φ
Bank Stability Factor =K1
Median riprap particle size (m) for Stabilty Factor of 1.2 = D50
use larger Stability Factor if applying at channel bends

Stability Factors (SF) and Correction Factor (C_{sf})

SF	C_{sf}	D_{50} (Φ = 41.2)	D_{50} (Φ = 41.6)	D_{50} (Φ = 41.8)	D_{50}| Φ = 42
1.0	0.76	**0.17**	**0.17**	**0.17**	**0.17**
1.1	0.88	**0.20**	**0.20**	**0.19**	**0.19**
1.2	1.00	**0.22**	**0.22**	**0.22**	**0.22**
1.3	1.13	**0.25**	**0.25**	**0.25**	**0.25**
1.4	1.26	**0.28**	**0.28**	**0.28**	**0.28**
1.5	1.40	**0.31**	**0.31**	**0.31**	**0.31**
1.6	1.54	**0.35**	**0.34**	**0.34**	**0.34**
1.7	1.69	**0.38**	**0.37**	**0.37**	**0.37**
1.8	1.84	**0.41**	**0.41**	**0.41**	**0.40**
1.9	1.99	**0.45**	**0.44**	**0.44**	**0.44**
2.0	2.15	**0.48**	**0.48**	**0.48**	**0.47**

Recommendation: Standard Riprap is adequate

Connecticut Department of Transportation

Project No.	**151-273 (Br.#01224)**	**Prepared by**	WS	**Date**	Oct. 2013
Route No.	**I-84**	**Checked by**		**Date**	
Town	**Waterbury**	**Stream**	Mad River		
Discharge	**100 Year**	**Unit**	Metric		

Riprap Revetment Design Based on HEC-11

$$D_{50} = 0.00594\ Va^3/(d_{avg} 0.5\ K_1^{1.5})\ C_{sf}$$

Average velocity (Va) and Average flow depth(d ave) in main channel

Cross Section No.	1153	Va (m/s)=	4.56
Flow Area (sq.m)=	38.85	Top Width (m)=	18.29
d avg (m) =	2.12		
Side Slope=	2 : 1	Bank angle (degrees) θ =	26.6

Riprap Class	Φ	K_1	D_{50}	Acceptable Range	Check
Modified	41.2	0.7342	**0.61**	d50 < 0.13m	NG
Intermediate	41.6	0.7391	**0.61**	0.13m<d50<0.20m	NG
Standard	41.8	0.7415	**0.61**	0.20m<d50<0.38m	NG
Other	42	0.7438	**0.60**	d50>0.38m	See Below

Assumed Specific Gravity of Rock Riprap = 2.65
Angle of Repose (degrees)= Φ
Bank Stability Factor =K1
Median riprap particle size (m) for Stabilty Factor of 1.2 = D50
use larger Stability Factor if applying at channel bends

Stability Factors (SF) and Correction Factor (C_{sf})

SF	C_{sf}	D_{50} (Φ = 41.2)	D_{50} (Φ = 41.6)	D_{50} (Φ = 41.8)	D_{50}| Φ = 42
1.0	0.76	**0.47**	**0.46**	**0.46**	**0.46**
1.1	0.88	**0.54**	**0.53**	**0.53**	**0.53**
1.2	1.00	**0.61**	**0.61**	**0.61**	**0.60**
1.3	1.13	**0.69**	**0.69**	**0.68**	**0.68**
1.4	1.26	**0.77**	**0.77**	**0.76**	**0.76**
1.5	1.40	**0.86**	**0.85**	**0.85**	**0.84**
1.6	1.54	**0.95**	**0.94**	**0.93**	**0.93**
1.7	1.69	**1.04**	**1.03**	**1.02**	**1.02**
1.8	1.84	**1.13**	**1.12**	**1.11**	**1.11**
1.9	1.99	**1.22**	**1.21**	**1.21**	**1.20**
2.0	2.15	**1.32**	**1.31**	**1.30**	**1.30**

Recommendation: The minimum d50 required for SF of 1 is 0.6 m, as computed above. The existing stream banks are protected with larger stones (in the range of 0.5 to 1 m) than Standard Riprap, and appear stable. The computed max. 100-yr flow velocity for the proposed condition is lower than that of the existing condition for the area downstream of the bridge. Therefore, the exsting revetment is deemed adequate.

Connecticut Department of Transportation

Project No.	**151-273 (Br.#01224)**	**Prepared by**	WS	**Date**	Oct. 2013
Route No.	**I-84**	**Checked by**		**Date**	
Town	**Waterbury**	**Stream**	Mad River		
Discharge	**500 Year**	**Unit**	Metric		

Riprap Revetment Design Based on HEC-11

$$D_{50} = 0.00594\ Va^3/(d_{avg} 0.5\ K_1^{1.5})\ C_{sf}$$

Average velocity (Va) and Average flow depth(d ave) in main channel

Cross Section No.	1277	Va (m/s)=	1.81
Flow Area (sq.m)=	174.06	Top Width (m)=	62.60
d avg (m) =	2.78		
Side Slope=	2 : 1	Bank angle (degrees) θ =	26.6

Riprap Class	Φ	K_1	D_{50}	Acceptable Range	Check
Modified	41.2	0.7342	**0.03**	d50 < 0.13m	G
Intermediate	41.6	0.7391	**0.03**	0.13m<d50<0.20m	G
Standard	41.8	0.7415	**0.03**	0.20m<d50<0.38m	G
Other	42	0.7438	**0.03**	d50>0.38m	

Assumed Specific Gravity of Rock Riprap = 2.65
Angle of Repose (degrees)= Φ
Bank Stability Factor =K1
Median riprap particle size (m) for Stabilty Factor of 1.2 = D50
use larger Stability Factor if applying at channel bends

Stability Factors (SF) and Correction Factor (C_{sf})

SF	C_{sf}	D_{50} (Φ = 41.2)	D_{50} (Φ = 41.6)	D_{50} (Φ = 41.8)	D_{50} | Φ = 42
1.0	0.76	**0.03**	**0.03**	**0.03**	**0.03**
1.1	0.88	**0.03**	**0.03**	**0.03**	**0.03**
1.2	1.00	**0.03**	**0.03**	**0.03**	**0.03**
1.3	1.13	**0.04**	**0.04**	**0.04**	**0.04**
1.4	1.26	**0.04**	**0.04**	**0.04**	**0.04**
1.5	1.40	**0.05**	**0.05**	**0.05**	**0.05**
1.6	1.54	**0.05**	**0.05**	**0.05**	**0.05**
1.7	1.69	**0.06**	**0.06**	**0.06**	**0.06**
1.8	1.84	**0.06**	**0.06**	**0.06**	**0.06**
1.9	1.99	**0.07**	**0.07**	**0.07**	**0.07**
2.0	2.15	**0.07**	**0.07**	**0.07**	**0.07**

Recommendation: Standard Riprap is adequate

Connecticut Department of Transportation

Project No.	**151-273 (Br.#01224)**	**Prepared by**	WS	**Date**	Oct. 2013
Route No.	**I-84**	**Checked by**		**Date**	
Town	**Waterbury**	**Stream**	Mad River		
Discharge	**500 Year**	**Unit**	Metric		

Riprap Revetment Design Based on HEC-11

$$D_{50} = 0.00594\ Va^3/(d_{avg} 0.5\ K_1^{1.5})\ C_{sf}$$

Average velocity (Va) and Average flow depth(d ave) in main channel

Cross Section No.	1214.5 BR U	Va (m/s)=	3.10
Flow Area (sq.m)=	87.31	Top Width (m)=	28.27
d avg (m) =	3.09		

Side Slope= 2 : 1

Bank angle (degrees)
θ = 26.6

Riprap Class	Φ	K_1	D_{50}	Acceptable Range	Check
Modified	41.2	0.7342	**0.16**	d50 < 0.13m	NG
Intermediate	41.6	0.7391	**0.16**	0.13m<d50<0.20m	G
Standard	41.8	0.7415	**0.16**	0.20m<d50<0.38m	G
Other	42	0.7438	**0.16**	d50>0.38m	

Assumed Specific Gravity of Rock Riprap = 2.65
Angle of Repose (degrees)= Φ
Bank Stability Factor =K1
Median riprap particle size (m) for Stabilty Factor of 1.2 = D50
use larger Stability Factor if applying at channel bends

Stability Factors (SF) and Correction Factor (C_{sf})

SF	C_{sf}	D_{50} (Φ = 41.2)	D_{50} (Φ = 41.6)	D_{50} (Φ = 41.8)	D_{50}| Φ = 42
1.0	0.76	**0.12**	**0.12**	**0.12**	**0.12**
1.1	0.88	**0.14**	**0.14**	**0.14**	**0.14**
1.2	1.00	**0.16**	**0.16**	**0.16**	**0.16**
1.3	1.13	**0.18**	**0.18**	**0.18**	**0.18**
1.4	1.26	**0.20**	**0.20**	**0.20**	**0.20**
1.5	1.40	**0.22**	**0.22**	**0.22**	**0.22**
1.6	1.54	**0.25**	**0.24**	**0.24**	**0.24**
1.7	1.69	**0.27**	**0.27**	**0.27**	**0.26**
1.8	1.84	**0.29**	**0.29**	**0.29**	**0.29**
1.9	1.99	**0.32**	**0.32**	**0.31**	**0.31**
2.0	2.15	**0.34**	**0.34**	**0.34**	**0.34**

Recommendation: Standard Riprap is adequate

Connecticut Department of Transportation

Project No.	**151-273 (Br.#01224)**	**Prepared by**	WS	**Date**	Oct. 2013
Route No.	**I-84**	**Checked by**		**Date**	
Town	**Waterbury**	**Stream**	Mad River		
Discharge	**500 Year**	**Unit**	Metric		

Riprap Revetment Design Based on HEC-11

$$D_{50} = 0.00594\ Va^3/(d_{avg} 0.5\ K_1^{1.5})\ C_{sf}$$

Average velocity (Va) and Average flow depth(d ave) in main channel

Cross Section No.	1214.5 BR D	Va (m/s)=	3.03
Flow Area (sq.m)=	88.82	Top Width (m)=	28.56
d avg (m) =	3.11		
Side Slope=	2 : 1	Bank angle (degrees) θ =	26.6

Riprap Class	Φ	K_1	D_{50}	Acceptable Range	Check
Modified	41.2	0.7342	**0.15**	d50 < 0.13m	NG
Intermediate	41.6	0.7391	**0.15**	0.13m<d50<0.20m	G
Standard	41.8	0.7415	**0.15**	0.20m<d50<0.38m	G
Heavy Riprap	42	0.7438	**0.15**	d50>0.38m	See Below

Assumed Specific Gravity of Rock Riprap = 2.65
Angle of Repose (degrees)= Φ
Bank Stability Factor =K1
Median riprap particle size (m) for Stabilty Factor of 1.2 = D50
use larger Stability Factor if applying at channel bends

Stability Factors (SF) and Correction Factor (C_{sf})

SF	C_{sf}	D_{50} (Φ = 41.2)	D_{50} (Φ = 41.6)	D_{50} (Φ = 41.8)	D_{50}| Φ = 42
1.0	0.76	**0.11**	**0.11**	**0.11**	**0.11**
1.1	0.88	**0.13**	**0.13**	**0.13**	**0.13**
1.2	1.00	**0.15**	**0.15**	**0.15**	**0.15**
1.3	1.13	**0.17**	**0.17**	**0.17**	**0.16**
1.4	1.26	**0.19**	**0.19**	**0.18**	**0.18**
1.5	1.40	**0.21**	**0.21**	**0.21**	**0.20**
1.6	1.54	**0.23**	**0.23**	**0.23**	**0.22**
1.7	1.69	**0.25**	**0.25**	**0.25**	**0.25**
1.8	1.84	**0.27**	**0.27**	**0.27**	**0.27**
1.9	1.99	**0.30**	**0.29**	**0.29**	**0.29**
2.0	2.15	**0.32**	**0.32**	**0.32**	**0.31**

Recommendation:

The minimum d50 required for SF of 1 is 0.5 m, as computed above. The existing stream banks are protected with larger stones (in the range of 0.5 to 1 m) than Standard Riprap, and appear stable. The computed 500-year flow velocity for the proposed condition is lower than that of the existing condition. Therefore, the exsting revetment is deemed adequate.

Connecticut Department of Transportation

Project No.	**151-273 (Br.#01224)**	**Prepared by**	WS	**Date**	Oct. 2013
Route No.	**I-84**	**Checked by**		**Date**	
Town	**Waterbury**	**Stream**	Mad River		
Discharge	**500 Year**	**Unit**	Metric		

Riprap Revetment Design Based on HEC-11

$$D_{50} = 0.00594\ Va^3/(d_{avg} 0.5\ K_1^{1.5})\ C_{sf}$$

Average velocity (Va) and Average flow depth(d ave) in main channel

Cross Section No.	1162	Va (m/s)=	4.46
Flow Area (sq.m)=	58.54	Top Width (m)=	21.03
d avg (m) =	2.78		
Side Slope=	2 : 1	Bank angle (degrees) θ =	26.6

Riprap Class	Φ	K_1	D_{50}	Acceptable Range	Check
Modified	41.2	0.7342	**0.50**	d50 < 0.13m	**NG**
Intermediate	41.6	0.7391	**0.50**	0.13m<d50<0.20m	**NG**
Standard	41.8	0.7415	**0.49**	0.20m<d50<0.38m	**NG**
Other	42	0.7438	**0.49**	d50>0.38m	**See Below**

Assumed Specific Gravity of Rock Riprap = 2.65
Angle of Repose (degrees)= Φ
Bank Stability Factor =K1
Median riprap particle size (m) for Stabilty Factor of 1.2 = D50
use larger Stability Factor if applying at channel bends

Stability Factors (SF) and Correction Factor (C_{sf})

SF	C_{sf}	D_{50} (Φ = 41.2)	D_{50} (Φ = 41.6)	D_{50} (Φ = 41.8)	D_{50}| Φ = 42
1.0	0.76	**0.38**	**0.38**	**0.38**	**0.37**
1.1	0.88	**0.44**	**0.44**	**0.43**	**0.43**
1.2	1.00	**0.50**	**0.50**	**0.49**	**0.49**
1.3	1.13	**0.57**	**0.56**	**0.56**	**0.56**
1.4	1.26	**0.63**	**0.63**	**0.62**	**0.62**
1.5	1.40	**0.70**	**0.69**	**0.69**	**0.69**
1.6	1.54	**0.77**	**0.77**	**0.76**	**0.76**
1.7	1.69	**0.85**	**0.84**	**0.83**	**0.83**
1.8	1.84	**0.92**	**0.91**	**0.91**	**0.90**
1.9	1.99	**1.00**	**0.99**	**0.99**	**0.98**
2.0	2.15	**1.08**	**1.07**	**1.06**	**1.06**

Recommendation: The minimum d50 required for SF of 1 is 0.4 m, as computed above. The existing stream banks are protected with larger stones (in the range of 0.5 to 1 m) than Standard Riprap, and appear stable. The computed 500-year flow velocity for the proposed condition is lower than that of the existing condition. Therefore, the exsting revetment is deemed adequate.

Connecticut Department of Transportation

Project No.	**151-273 (Br.#01224)**	**Prepared by**	WS	**Date**	Oct. 2013
Route No.	**I-84**	**Checked by**		**Date**	
Town	**Waterbury**	**Stream**	Mad River		
Discharge	**500 Year**	**Unit**	Metric		

Riprap Revetment Design Based on HEC-11

$$D_{50} = 0.00594\ Va^3/(d_{avg} 0.5\ K_1^{1.5})\ C_{sf}$$

Average velocity (Va) and Average flow depth(d ave) in main channel

Cross Section No.	1153	Va (m/s)=	4.82
Flow Area (sq.m)=	52.43	Top Width (m)=	18.41
d avg (m) =	2.85		
Side Slope=	2 : 1	Bank angle (degrees) θ =	26.6

Riprap Class	Φ	K_1	D_{50}	Acceptable Range	Check
Modified	41.2	0.7342	**0.63**	d50 < 0.13m	NG
Intermediate	41.6	0.7391	**0.62**	0.13m<d50<0.20m	NG
Standard	41.8	0.7415	**0.62**	0.20m<d50<0.38m	NG
Other	42	0.7438	**0.61**	d50>0.38m	See Below

Assumed Specific Gravity of Rock Riprap = 2.65
Angle of Repose (degrees)= Φ
Bank Stability Factor =K1
Median riprap particle size (m) for Stabilty Factor of 1.2 = D50
use larger Stability Factor if applying at channel bends

Stability Factors (SF) and Correction Factor (C_{sf})

SF	C_{sf}	D_{50} (Φ = 41.2)	D_{50} (Φ = 41.6)	D_{50} (Φ = 41.8)	D_{50}| Φ = 42
1.0	0.76	**0.48**	**0.47**	**0.47**	**0.47**
1.1	0.88	**0.55**	**0.54**	**0.54**	**0.54**
1.2	1.00	**0.63**	**0.62**	**0.62**	**0.61**
1.3	1.13	**0.71**	**0.70**	**0.70**	**0.69**
1.4	1.26	**0.79**	**0.78**	**0.78**	**0.77**
1.5	1.40	**0.88**	**0.87**	**0.86**	**0.86**
1.6	1.54	**0.96**	**0.96**	**0.95**	**0.95**
1.7	1.69	**1.06**	**1.05**	**1.04**	**1.04**
1.8	1.84	**1.15**	**1.14**	**1.13**	**1.13**
1.9	1.99	**1.25**	**1.24**	**1.23**	**1.22**
2.0	2.15	**1.35**	**1.33**	**1.33**	**1.32**

Recommendation: The minimum d50 required for SF of 1 is 0.6 m, as computed above. The existing stream banks are protected with larger stones (in the range of 0.5 to 1 m) than Standard Riprap, and appear stable. The computed max. 500-yr flow velocity for the proposed condition is lower than that of the existing condition for the area downstream of the bridge. Therefore, the exsting revetment is deemed adequate.

U.S. Army Corps of Engineers Procedure

This procedure is based on the U.S. Army Corps of Engineers' *Hydraulic Design of Flood Control Channels*, EM 1110-2-1601, July 1, 1991. The procedure is based on depth-averaged local velocity. The basic equation is:

$$D_{30} = S_f \; C_S \; C_V \; C_T \; d \; \{[(\gamma_w / (\gamma_s - \gamma_w)]^{1/2} \; [V / (K_1 \; g \; d)^{1/2}]\}^{2.5} \qquad \text{(Equation 3-3)}$$

where,

Variable	Variable Description	Q100	Q500	Notes
S_f	safety factor	1.1	1.0	
C_S	stability coefficient for incipient failure	0.3	0.3	0.375 for rounded, 0.30 for angular stone
C_V	vertical velocity distribution coefficient	1.1	1.1	= 1.283 - 0.2 log (R/W) for outside of bends (= 1 for R/W > 26)
R	center-line radius of bend	100 m	100 m	
W	water-surface width	18.29 m	18.41 m	main channel only
C_T	thickness coefficient	1.0	1.0	= 1 if thickness = $1D_{100}$ (or $1.5D_{50}$)
d	local depth of flow	2.12 m	2.85 m	from HEC-RAS at cross section 1153
γ_w	unit weight of water	1000 kg/m^3	1000 kg/m^3	
γ_s	unit weight of stone	2643 kg/m^3	2643 kg/m^3	= 165 pcf
V	local depth-averaged velocity	4.56 m/s	4.82 m/s	from HEC-RAS at cross section 1153
V_{ss}	design velocity	4.56 m/s	4.82 m/s	Use Local Velocity
K_1	side slope correction factor	0.7415	0.7415	Side Slope = 2:1 Repose angle Φ(°)= 41.8
g	gravitational constant	9.81 m/s^2	9.81 m/s^2	
D_{30}	**riprap size**	**0.62 m**	**0.60 m**	using Equation 3-3
D_{50}		**0.74 m**	**0.72 m**	

Page 2-13 recommends that to maintain tranquil flow through curves in the watercourse the ratio of the curve radius to channel width be 3 or greater. Therefore,

	Q100	Q500	Notes
R/W =	5.5	5.4	> 3 for tranquil flow

R/W is greater than 3, thus, the flow is tranquil for Q100
R/W is greater than 3, thus, the flow is tranquil for Q500

From Table 3-1 the recommended gradation, assuming γ = 165 pcf is:

(linearly interpolated)

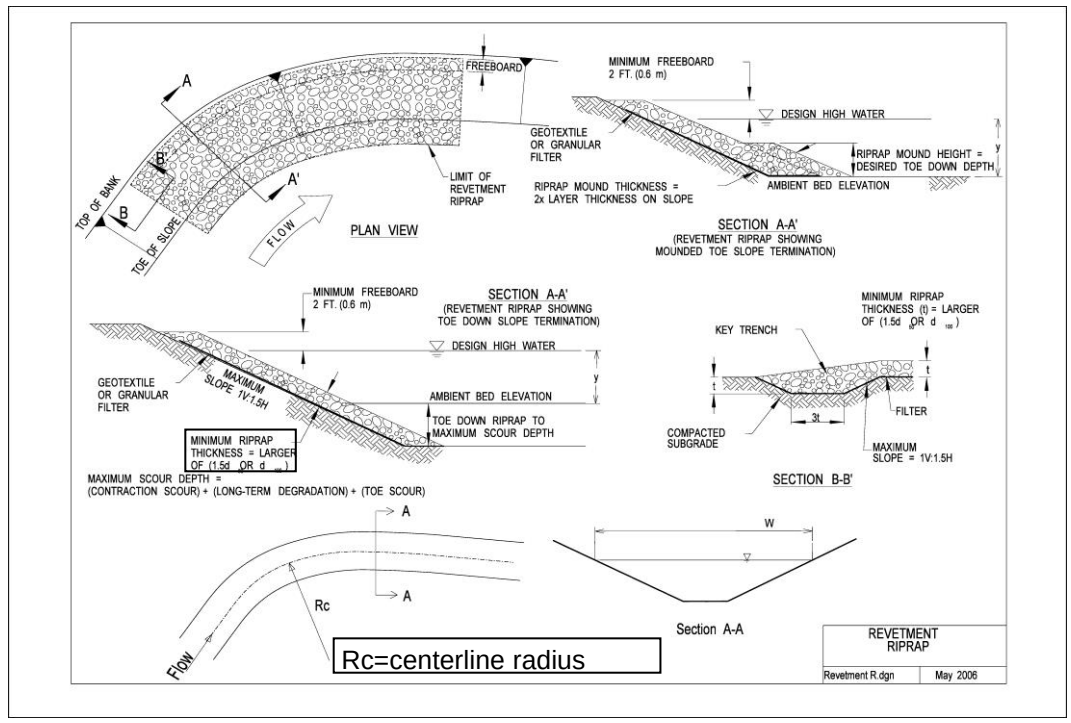
	Riprap Size (m)	
	Q100	Q500
D_{30}	0.62	0.60
D_{90}	0.90	0.87
D_{100}	1.27	1.24

CONNECTICUT DEPARTMENT OF TRANSPORTATION

			Desgin Freq.:	100-YR	
Project No.	151-273	**Prepared by**	ws	Date	Oct. 2013
Route No.	I-84	**Checked by**		Date	
Town	Waterbury	**Stream**	Mad River		

Supporting File:Refer to Appendix C of NCHRP_Report 568 (Click link)

..\Manuals & Publications\NCHRP\Riprap Design Criteria, Recommer pages C-1 to C-36 of Report 568



DESIGN PARAMETERS

Note: C_t=1 is recommended because it is based on very limited data(as a function of the uniformity ratio d_{85}/d_{15})

Enter g=9.81m/s^2 and Sg=2.65 as given

	Cross Section No.	1153		Bank Angle (degrees)	θ =	26.6	
	Side Slope =	2	: 1	Ave. channel velocity	V_{ave}=	4.56	m/s
Rc	Centerline Radius=	100	m	Flow depth at bank toe	y=	2.12	m
W	Width of W.S =	18.29	m	Blanket thickness coef.	C_T=	1	
	Rc/W=	5.467469		Sp. Gravity of riprap	S_g=	2.65	
S_f=	Safety factor	1.1		Acceleration due to gravity	g=	9.81	m/s^2

$$K_1 = \sqrt{1 - \left[\frac{\sin(\theta - 14^0)}{\sin(32^0)}\right]^{1.6}} = 0.87$$

Side slope Correction factor or select from graph on Plate B-39 of EM 1601

Cs= 0.3 = 0.30 for angular rock
=0.375 for rounded rock

Stability Coefficient (for blanket thickness = d_{100} or $1.5d_{50}$, whichever is greater and uniformity ratio d_{85}/d_{15}= 1.7 to 5.2)

Velocity distribution Coefficient

Cv= 1.14 =1.0 for straight channels or the inside of bends
=1.283-0.2log(Rc/W) for the outside of bends (1 for Rc/W>26) 1.14
=1.25 downstream from concrete channels
=1.25 at the end of dikes

V_{des}= 4.56 =V_{ave}(1.74 - 0.52log(Rc/W)) for natural channels 6.18
=V_{ave}(1.71 - 0.78log(Rc/W)) for trapezoidal channels 5.17

$$d_{30} = y(S_f C_s C_v C_T)\left[\frac{V_{des}}{\sqrt{k_1 (S_g - 1) g y}}\right]^{2.5}$$

Note:Limition of this equation
Longitudinal slope of the channel should not be steeper than 2% 0.50

d_{50}= 609.6 mm (= 24 in) (=1.20 x d_{30} m = 23.8 inches) 0.61

Minimum riprap thickness= larger of ($1.5d_{50}$ or d_{100})

Select riprap in Table C8.1 go to next tab VII

Determine the depth of riprap embedment below the streambed at the toe of the bank slope
(refer to figure above)

Filter Layer Check
Bridge No. 01224

Riprap Filter Design

The following design is based on a method presented in HEC-15(SI) and HEC-11(SI).

Granular Filter Blanket
HEC-15(SI) gives the following criteria for the design of a granular filter blanket:

$[(D_{15})_{surface} / (d_{85})_{subbase}] < 5 < [(D_{15})_{surface} / (d_{15})_{subbase}] < 40$ (Equation 11)

and,

$[(D_{50})_{surface} / (d_{50})_{subbase}] < 40$ (Equation 12)

Geotextile Filter
For a geotextile filter HEC-15(SI) recommends the following:

For $(d_{50})_{subbase} > 0.075$mm, use a geotextile with an AOS < 0.6mm.

For $(d_{50})_{subbase} < 0.075$mm, use a geotextile with an AOS < 0.297mm.

Surface Material =	Standard Riprap
Subbase =	Granular Fill

Granular Filter

$(D_{15})_{surface}$	=	100	mm
$(D_{50})_{surface}$	=	380	mm
$(d_{15})_{subbase}$	=	0.48	mm
$(d_{50})_{subbase}$	=	9	mm
$(d_{85})_{subbase}$	=	64	mm

$\frac{(D_{15})_{surface}}{(d_{85})_{subbase}} = 1.6$ **Filter satisfies design criteria from Equation 11.**

$\frac{(D_{15})_{surface}}{(d_{15})_{subbase}} = 208.3$ **Filter does not satisfy design criteria from Equation 11.**

$\frac{(D_{50})_{surface}}{(d_{50})_{subbase}} = 42.2$ **Filter does not satisfy design criteria from Equation 12.**

Geotextile Filter

(d50)subbase > 0.075mm, use a geotextile with an AOS < 0.6mm.

Filter Layer Check
Bridge No. 01224

Subbase Filter Design

The following design is based on a method presented in HEC-15(SI) and HEC-11(SI).

Granular Filter Blanket
HEC-15(SI) gives the following criteria for the design of a granular filter blanket:

$[(D_{15})_{surface} / (d_{85})_{subbase}] < 5 < [(D_{15})_{surface} / (d_{15})_{subbase}] < 40$ (Equation 11)

and,

$[(D_{50})_{surface} / (d_{50})_{subbase}] < 40$ (Equation 12)

Geotextile Filter
For a geotextile filter HEC-15(SI) recommends the following:

For $(d_{50})_{subbase} > 0.075$mm, use a geotextile with an AOS < 0.6mm.

For $(d_{50})_{subbase} < 0.075$mm, use a geotextile with an AOS < 0.297mm.

Surface Material =	Granular Fill
Subbase =	Native Material

Granular Filter

$(D_{15})_{surface}$	=	0.48	mm
$(D_{50})_{surface}$	=	9	mm
$(d_{15})_{subbase}$	=	0.12	mm
$(d_{50})_{subbase}$	=	0.7	mm
$(d_{85})_{subbase}$	=	18.5	mm

$\frac{(D_{15})_{surface}}{(d_{85})_{subbase}} = 0.0$ **Filter satisfies design criteria from Equation 11.**

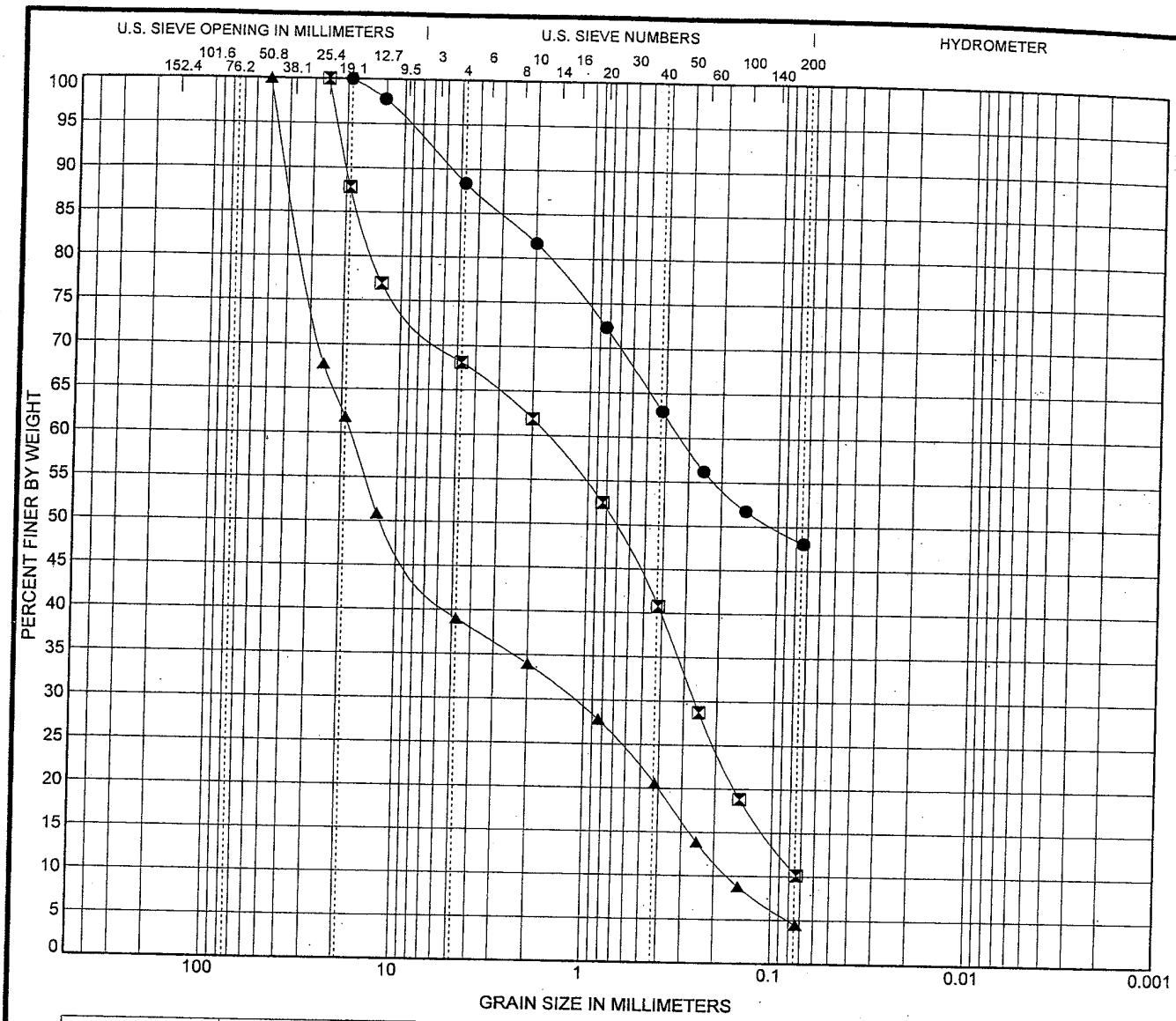
$\frac{(D_{15})_{surface}}{(d_{15})_{subbase}} = 4.0$ **Filter does not satisfy design criteria from Equation 11.**

$\frac{(D_{50})_{surface}}{(d_{50})_{subbase}} = 12.9$ **Filter satisfies design criteria from Equation 12.**

Geotextile Filter

(d50)subbase > 0.075mm, use a geotextile with an AOS < 0.6mm.

Soil Sample Analysis (Channel Bank)



	COBBLES	% GRAVEL			% SAND		% FINES	
		COARSE	MEDIUM	FINE	COARSE	FINE	% SILT	% CLAY
●	0.0	0.0	5.0	13.3	18.7	14.9	48.1	
⊠	0.0	0.0	25.7	12.4	21.1	30.6	10.2	
▲	0.0	32.2	20.4	13.4	13.4	16.0	4.5	

	Expl. No.	Sample No.	Depth (m)	LL	PL	PI	Water Content (%)	Cc	Cu
●	S4-2	D1	0.0-0.61				6.2		
⊠	S4-3	D1	0.0-0.61				6.3		
▲	S4-7	D2	1.52-2.13				4.9	0.44	106.24

	Sample Description
●	Coarse to fine SAND, some gravel, little silt - FILL
⊠	Coarse to fine SAND, little gravel, trace silt - FILL
▲	Coarse to fine GRAVEL, some sand, trace silt - FILL

Remarks:

HALEY & ALDRICH
Glastonbury, Connecticut

U.S. Interstate Route 84 Reconstruction
Waterbury, Connecticut
State Project No.: 151-273

GRAIN SIZE DISTRIBUTION

Date: 4/16/2001

File No.: 91313-100

CONN DOT SIEVE 91313SA.GPJ US LAB.GDT 3/6/02

E. Del Priore DRILLER	SM - 001 - M REV. 1/94 BORING REPORT STATE OF CONNECTICUT DEPARTMENT OF TRANSPORTATION	Hole No. **S4-3**
P. Carrera INSPECTOR		Line & Station
		Offset
Haley & Aldrich, Inc. SOILS ENGINEER	TOWN: **Waterbury, CT**	N. Coordinate **230905.58**
	PROJECT NAME: **Reconstruction of I-84**	E. Coordinate **282461.88**
	PROJECT NUMBER: **State: 151-273/H&A: 91313-102**	**Berger, Lehman Associates, P.C.**
	BORING CONTRACTOR: **General Borings, Inc.**	PRIME DESIGNER

		Casing				Auger		Mud	Sampler		Core Barrel			
Surface Elevation: **106.73**	Utilized		X						X					X
Date Started: **21 November 2000**	Type	BW	NW	HW	Pipe	Solid	Hollow		SS		B(st)	B(dt)	NX(st)	NX(dt)
Date Finished:	Size I.D. (mm)	60	76	100	64				35	X	35	35	55	55
Groundwater Observations	Hammer (kg)	136	136	136	136			Bit	63.5		Type		Diamond	
@ **5.03** m after **0** hours	Fall (m)	0.6	0.6	0.6	0.6				0.76		of bit		Carbide	
@ m after hours														

DEPTH	Casing blows per half meter	SAMPLE DEPTH IN METERS FROM - TO	NO.	PEN. m	REC m	Type	BLOWS PER 0.15 METERS ON SAMPLER 0-0.15	0.15-0.30	0.30-0.45	0.45-0.60	STRATA CHANGE ELEV./DEPTH (m)	FIELD IDENTIFICATION OF SOIL REMARKS (INCL. COLOR, LOSS OF WASH WATER, ETC.)
		0.00-0.61	1	0.61	0.61	D	3	6	8	11		Medium dense brown coarse to fine SAND, little gravel, trace silt
											105.23	-FILL-
		1.52-2.13	2	0.61	0.45	D	17	20	25	28	1.50	Dense brown coarse to fine SAND, little fine gravel with cobbles
		3.05-3.35	3	0.30	0.00	D	29	100/0.15				No Recovery
5		4.57-4.72	4	0.15	0.15	D	100					Very dense brown medium to fine GRAVEL, some coarse to fine sand, trace silt with cobbles
											100.63	
		6.10-6.71	5	0.61	0.45	D	14	14	15	13	6.10	Medium dense brown coarse to fine SAND, trace silt Boulder from 7.7 m - 8.53 m
		7.62-7.70	6	0.08	0.00	D	100/.08					
10		9.14-9.45	7	0.31	0.15	D	31	100				Very dense brown coarse to fine SAND, some medium to fine gravel with cobbles
		10.67-10.82	8	0.15	0.15	D	100/.15					Very dense brown coarse to fine SAND and fine gravel, trace medium gravel
											94.54	-GLACIOFLUVIAL DEPOSITS-
		12.19-12.19	9	0.00	0.00	D	100/0				12.19	C1: Hard, fresh, gray and white coarse to fine grained granitic GNEISS. Foliation is moderately dipping, extremely close. Joints are moderately dipping to high angle, close to moderate, rough, undulating, fresh, open
		13.11-14.63	1	1.52	1.36	C		[RQD = 64%]				
15		14.63-16.15	2	1.52	1.52	C		[RQD = 64%]				C2: Same as C1 except joints are low to high

Casing Size	From	To	Meters of Earth	Rock
NW	**0.0**	**13.11**	**13.11** m	**3.04** m
			No. of Samples	
			9D,2C	

NOTES: **Bomb mounted Diedrich D-120 with wire winch to drive safety hammer. Borehole backfilled with drill cuttings upon completion.**

SAMPLE TYPE CODING: D=Driven C=Core A=Auger UP=Undisturbed Piston V=Vane Test SS=Split Spoon
PROPORTIONS USED: Trace=1-10% Little=10-20%, Some=20-35%, And=35-50%

Hole No. **S4-3**
Sheet **1** of **2**